WHITE PAPER

Scoping Assessment for Developing a Water Quality Monitoring Plan to Support Application of the CE-QUAL-W2 Hydrodynamic and Water Quality Model to the Lower Missouri River downstream of Gavins Point Dam

U.S. Army Corps of Engineers – Omaha District
U.S. Army Corps of Engineers – Kansas City District

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1 CORPS OPERATIONS AND PROGRAMS AND MISSOURI RIVER WATER QUALITY

1.1 MISSOURI RIVER MAINSTEM SYSTEM

The Missouri River Mainstem System (Mainstem System) is comprised of six dams and reservoirs constructed by the U.S. Army Corps of Engineers (USACE) on the Missouri River, and where present, the free-flowing Missouri River downstream of the dams. The six reservoirs impounded by the dams contain about 73.3 million acre-feet of storage capacity and, at normal pool, an aggregate water surface area of about 1 million acres. The six dams and reservoirs in an upstream to downstream order are: Fort Peck Dam and Fort Peck Lake (MT), Garrison Dam and Lake Sakakawea (ND), Oahe Dam (SD) and Lake Oahe (ND and SD), Big Bend Dam and Lake Sharpe (SD), Fort Randall Dam and Lake Francis Case (SD), and Gavins Point Dam and Lewis and Clark Lake (SD and NE). The Mainstem System is a hydraulically and electrically integrated system that is regulated to obtain the optimum fulfillment of the multipurpose benefits for which the dams and reservoirs were authorized and constructed. The Congressionally authorized purposes of the Mainstem System are flood control, navigation, hydropower, water supply, water quality, irrigation, recreation, and fish and wildlife (including threatened and endangered species). The Mainstem System is operated under the guidelines described in the Missouri River Mainstem System Master Water Control Manual (Master Manual) (USACE-RCC, 2006). Flow in the lower Missouri River is largely determined by the discharge of Gavins Point Dam, especially so during low-flow periods.

1.2 MISSOURI RIVER RECOVERY PROGRAM

The U.S. Fish and Wildlife Service (USFWS) issued a Biological Opinion (BiOp) with requirements for the USACE operations of the Mainstem System for protection and enhancement of threatened and endangered species. The Missouri River Recovery Program (MRRP) is being implemented by the USACE to address these requirements. The MRRP's vision for the Missouri River is a sustainable ecosystem that supports thriving populations of native species while providing for current social and economic values. Key initiatives for the MRRP are: habitat creation, hatchery support, flow modification, science program, and public involvement. Regarding habitat creation, the goal of the MRRP is to provide habitat for native fish and wildlife by restoring natural features and functions. This includes establishing shallow water and sandbar habitat and restoring riparian cottonwood stands. Operation of the Mainstem System has altered natural flows in the Missouri River which have affected important ecosystem functions. A goal of the MRRP is to implement a more natural flow regime to benefit native fish and wildlife while seeking balance with social, economic, and cultural resources. It is also a goal of the MRRP that management decisions are based on the best available science and responsive to adaptive management.

The BiOp found that the USACE operation of the Mainstem System jeopardizes the continued existence of the endangered pallid sturgeon *(Scaphirhynchus albus)* in the wild. The BiOp concluded that the operation of the Mainstem System, including the construction and maintenance of a navigation channel, has jeopardized the pallid sturgeon by reducing habitat diversity, regulating flows, and reducing sediment and nutrient transport and turbidity in the lower Missouri River. Under the BiOp, the USFWS identified several Reasonable and Prudent Alternatives (RPA) that the USACE must implement to remove the jeopardy to pallid sturgeon. The BiOp also found that the USACE operation of the Mainstem System was not likely to jeopardize the endangered interior least tern *(Sterna antillarum)* and threatened piping plover *(Charadrius melodus)* populations if the RPAs set forth in the BiOp were implemented.

1.3 DISTRICT WATER QUALITY MANAGEMENT PROGRAMS

The Omaha and Kansas City Districts are implementing Water Quality Management Programs (WQMP) as part of the operation and maintenance activities associated with managing the USACE civil works projects in the Districts. The District WQMPs address water quality management issues and adhere to the guidance and requirements specified in the USACE Engineering Regulation – ER 1110-2-8154, "Water Quality and Environmental Management for Corps Civil Works Projects" (USACE, 1995). ER 1110-2-8154 requires that specific water quality management objectives be developed for each Corps Project and procedures established and implemented to meet those objectives. Water quality management objectives are to address, among other things, the following:

- Ensure that water quality, as affected by the project and its operation, is suitable for project purposes, existing water uses, and public health and safety and is in compliance with applicable Federal, Tribal, and State water quality standards.
- Establish and maintain a water quality monitoring and data evaluation program that ensures achievement of water quality management objectives and facilitates evaluation of project performance and water quality trends.
- Identify existing and potential water quality problems, and develop and implement appropriate solutions. Identify opportunities for water quality improvements to Projects or receiving waters and initiate management actions that accomplish those improvements.
- Integrate water quality considerations into all water control management decisions.
- Maintain close coordination and, where possible, collaboration with all interested governmental and nongovernmental entities with regard to activities that may affect or be affected by the water quality or control decisions associated with Corps Projects.
- Develop an understanding and continuing awareness of the water quality factors and processes in the Project, in the watershed, and in the area influenced by Project operation.
- Ensure that the Project and its operation offer the lowest stress possible to the aquatic environment.
- Develop predictive models of water quality response to Projects and their operations to allow design feedback and the development of adequate operating plans.

1.3.1 Priority Water Quality Management Issues Identified for the Omaha District Water Quality Management Program (USACE, 2010)

Several priority water quality management issues have been identified by the Omaha District to direct implementation of the District's Water Quality Management Program (WQMP). The Currently identified priority water quality management issues are:

- Determine how regulation of the Missouri River Mainstem System (Mainstem System) dams affects water quality in the impounded reservoir and downstream river. Utilize the CE-QUAL-W2 hydrodynamic and water quality model to facilitate this effort.
- Evaluate how eutrophication is progressing in the Mainstem System reservoirs, especially regarding the expansion of anoxic conditions in the hypolimnion during summer stratification.
- Determine how flow regime, especially the release of water from Mainstem System projects, affects water quality in the Missouri River.

- Provide water quality information to support Corps reservoir regulation elements for effective surface water quality and aquatic habitat management.
- Provide water quality information and technical support to the Tribes and States in the development of their Section 303(d) lists and development and implementation of TMDLs at District Projects.
- Identify existing and potential surface water quality problems at District Projects and develop and implement appropriate solutions.
- Evaluate surface water quality conditions and trends at District Projects.
- Determine how current water quality conditions in the Missouri River (e.g., water temperature, turbidity, etc.) may be affecting pallid sturgeon populations in the Missouri River system.

1.3.2 Priority Water Quality Management Issues Identified for the Kansas City District Water Quality Management Program

The following water quality management issues have been identified by the Kansas City District for the Missouri River:

- Monitor status and trends of water quality conditions within the Missouri River, selected tributaries, and shallow water habitat sites.
- Determine if surface water quality conditions of Missouri River meet all applicable federal and state water quality standards.
- Quantify any surface water quality concerns within the Missouri River to determine future needs.
- Participate in collaborative efforts to develop a restoration plan when surface water quality conditions dictate.
- Provide data in a timely manner to support Missouri River operations that enhance surface water quality for the ambient aquatic environment.
- Determine if water quality is a potential limiting factor for the recovery of fish and wildlife populations along the Missouri River.

1.4 WATER QUALITY MODELING OF THE LOWER MISSOURI RIVER

The lower Missouri River is defined as the reach of the river from Gavins Point Dam downstream to the river's mouth near St. Louis, MO.

1.4.1 Application of the QUAL2E Water Quality Model

The USACE Waterways Experiment Station (WES, Vicksburg, MS) applied the U.S. Environmental Protection Agency's (USEPA) QUAL2E water quality model to the lower Missouri River in the early 1990's to support the review and update of the Master Water Control Manual for the Missouri River. The findings and recommendations of the model application were documented in the report *"Predicted Water Quality Impacts from Reducing Flow Out of Gavins Point on the Missouri River"* (Tillman, 1992). The modeling was used to assess the far field effects of reducing historical seasonal flows for a range of release temperatures on key water quality constituents (i.e., temperature, dissolved oxygen, CBOD, etc.) in the lower Missouri River. Sensitivity analyses were also simulated to examine how sensitive the Missouri River system was to changes in "boundary conditions" (i.e., tributary and point source flow and water quality conditions). Scenario testing found that under "extreme" conditions reductions in flow from Gavins Point Dam can have "significant" impacts on Missouri River water quality; however, all the modeled constituents were well within State water quality standards at the time.

A steady-flow/steady-state water quality modeling approach was selected for this previous modeling effort. Steady-flow means that flow does not change with time, but flow can change along the reach of the river modeled. Steady-state water quality means that water quality concentrations do not change with time, but can change with location along the modeled reach. A steady-state approach was selected for this previous modeling effort based on the following rationale:

- Most of the concerns for poor water quality resulting from reduction in Gavins Point Dam release flow would occur during dry, hot periods (i.e., drought). During these conditions it is a reasonable assumption that tributary inflows would be essentially constant from lack of rainfall and runoff.
- Release flows from Gavins Point Dam are relatively constant for extended periods of time.
- The assumption of steady-flow is a reasonable assumption.
- Steady-state loadings are usually associated with steady-flow.
- As in a waste load allocation study, pollutant loadings within a stream are modeled to determine the impact on instream water quality. In this study, release flows from Gavins Point Dam were varied between extreme limits, with waste loads unmodified, to determine impacts on water quality.
- Steady-state models require far less data and effort to calibrate and verify than required for dynamic (i.e., time-varying) models. Available water quality data for the lower Missouri River were limited, and water quality data had to be collected. Two “snap-shot” sampling efforts were conducted in the late summer of 1990 to collect the data needed to “calibrate” and “verify” the QUAL2E model.

The applied QUAL2E model was a one-dimensional, steady-state riverine water quality model. With this type of model, water quality assessments are limited by the assumptions of the model, mainly steady-flow and steady-state conditions. This is believed a valid modeling approach for assessing steady-state “low-flow” conditions. However, improvements in dynamic water quality models in the past 20 years have made their application less onerous, and dynamic modeling is more representative of “real” conditions. The earlier developed QUAL2E model has not been maintained or further verified with more recently collected water quality data.

1.4.2 Proposed Application of the CE-QUAL-W2 Hydrodynamic and Water Quality Model

CE-QUAL-W2 is a “state-of-the-art” two-dimensional (i.e., longitudinal and vertical), laterally averaged, hydrodynamic and water quality model for rivers, estuaries, lakes, reservoirs, and river basin systems. It models basic physical, chemical, and biological processes such as temperature, nutrient, algae, dissolved oxygen, organic matter, and sediment relationships. Version 1.0 of the model was developed by the USACE “Water Quality Modeling Group” at the Waterways Experiment Station (WES) in Vicksburg, MS in the late 1980’s. The current release is Version 3.6 and is supported by the USACE Engineer Research and Development Center (ERDC), Environmental Laboratory, Water Quality and Contaminant Modeling Branch and the “Water Quality Research Group” at Portland State University Portland, OR.

The CE-QUAL-W2 model is currently being applied to the Missouri River Mainstem System by the Omaha District. The model is being applied to enhance assessment of water quality conditions and to objectively evaluate how reservoir regulation impacts water quality at the District’s Mainstem System Projects. It is believed that a maintained CE-QUAL-W2 model that reflects current conditions can be a valuable tool for water quality management at the

District's Missouri River Mainstem Projects. The goal is to have linked models in place for all the Mainstem System reservoirs and selected Missouri River reaches that are "current" and meet the uncertainty requirements of decision-makers. To date, the CE-QUAL-W2 model has been applied to Garrison and Fort Peck Reservoirs, and partial applied to the Missouri River downstream of Fort Peck Dam. Intensive water quality surveys to collect water quality data to facilitate future application of the model have been conducted at Oahe and Fort Randall Reservoirs and are ongoing at Big Bend and Gavins Point Reservoirs. A water quality monitoring plan is currently under development to collect the water quality data needed to apply the model to the lower Missouri River.

It is believed application of the CE-QUAL-W2 model to the lower Missouri River will allow the District to better assess how regulating flows at Gavins Point Dam impact water quality. Maintenance of the model, once developed, will provide the District a "tool" to assess flow regulation in response to changing water quality management needs along the river. In general, the purpose of the model will be to objectively evaluate the downstream, far-field effects of flow regulation at Gavins Point Dam. The model may also allow for the assessment of the potential impacts that constructed MRRP projects may be having on water quality in the lower Missouri River.

Applying the CE-QUAL-W2 model to the lower Missouri River will address the following four identified priority water quality management issues for the Omaha District *(2010Program Management Plan for the Omaha District Water Quality Management Program)*:

1) Determine how regulation of the Missouri River Mainstem System dams affects water quality in the impounded reservoir and downstream river. Utilize the CE-QUAL-W2 hydrodynamic and water quality model to facilitate this effort.
2) Determine how flow regime, especially the release of water from Mainstem System projects, affects water quality in the Missouri River.
3) Provide water quality information to support Corps reservoir regulation elements for effective surface water quality and aquatic habitat management.
4) Determine how current water quality conditions in the Missouri River (e.g., water temperature, turbidity, etc.) may be affecting pallid sturgeon populations in the Missouri River system.

A primary question that model application would seek to answer is: *How does water quality in the lower Missouri River respond to the regulation of flows from Gavins Point Dam*? It is generally believed that flow regulation will have the greatest water quality impact during "low-flow" periods when tributary inflows are reduced. Typical "low-flow" periods in the Missouri River basin occur during drought conditions and during the winter. Summer drought conditions are especially concerning as this is a time when elevated water temperatures and oxygen demand could become a limiting factor to the water quality-dependent beneficial uses ascribed to the lower Missouri River in State water quality standards. During "low-flow" periods, the regulation of releases at Gavins Point Dam largely determines the assimilative capacity (i.e., pollution loading capacity) of the lower Missouri River.

1.4.3 Application of the CORMIX Mixing Zone Water Quality Model

In the recent past, the USEPA applied the CORMIX mixing zone model to assess the potential impact of power plant thermal discharges on the water quality of the lower Missouri River. They concluded that changes in the flow regime can effect site-specific pollutant calculations, but not by huge amounts (personal communication, John Dunn, USEPA Region 7). It was also concluded that during very "hot" summers lower flows in the lower Missouri River

can result in a “hotter” river. However, there was uncertainty as to what degree lower flows would cause or contribute to warmer river conditions.

2 LOWER MISSOURI RIVER REACH CHARACTERISTICS, FLOW REGULATION, AND THREATENED AND ENDANGERED SPECIES CONCERNS

2.1 REACH CHARACTERISTICS

The lower Missouri River can be divided into three distinctive reaches: 1) Missouri National Recreation River (MNRR) reach, 2) Kensler’s Bend reach, and 3) Navigation Channel reach. The 59-mile reach of the Missouri River from Gavins Point Dam, starting at River Mile (RM) 811, downstream to Ponca, NE (RM752) has been designated a National Recreational River under the Federal Wild and Scenic Rivers Act. This reach of the river has not been channelized by construction of dikes and revetments, and has a meandering channel with many chutes, backwater marshes, sandbars, islands, and variable current velocities. Snags and deep pools are also common. Although this portion of the river includes some bank stabilization structures, the river remains fairly wide. The Kensler’s Bend reach of the Missouri River extends from Ponca, NE (RM752) to above Sioux City, IA (RM735). The Missouri River banks have been stabilized with dikes and revetments through this reach, but it has not been channelized. The reach of the Missouri River from the end of the Kensler’s Bend reach (RM735) to the rivers mouth near St. Louis, MO has been modified over its entire length by an intricate system of dikes and revetments designed to provide a continuous navigation channel without the use of locks and dams. This reach is managed by the USACE under the Missouri River Bank Stabilization and Navigation Project. In addition to the primary authorization to maintain a navigation channel (9 ft deep by 300 ft wide) downstream from Sioux City, IA, there are authorizations to stabilize the river’s banks.

2.2 FLOW REGULATION

Gavins Point Reservoir (i.e., Lewis and Clark Lake) is normally regulated near 1206.0 ft-msl in the spring and early summer with variations day to day due to rainfall runoff. The reservoir level is then increased to elevation 1207.5 ft-msl following the least tern and piping plover nesting season for reservoir recreation enhancement. Releases from Gavins Point Dam follow the same pattern as those from Fort Randall Dam because there is little active storage in Lewis and Clark Lake. Releases are based on the amount of water in Mainstem System storage, which governs how much water will be released to meet service demands in the portion of the lower Missouri River from Sioux City, IA to St. Louis, MO. Constraints for flood control, threatened and endangered bird nesting, and fish spawning also are factors governing releases. Releases from Gavins Point Dam generally fall into three categories: navigation, flood evacuation, and non-navigation releases.

2.2.1 Mainstem System Service Level

To facilitate appropriate application of multipurpose regulation criteria to the Mainstem System, a numeric “service level” has been adopted since the Mainstem System was first filled in 1967. Quantitatively, a full-service level approximates the water release rate necessary to achieve a normal 8-month navigation season with average downstream tributary flow contributions. For full-service and minimum-service levels, the numeric service level values are, 35,000 cfs (cubic feet per second) and 29,000 cfs, respectively. This service level is used for selection of appropriate flow target values at previously established downstream control locations on the Missouri River. There are four flow target locations selected below Gavins

Point Dam to assure that the lower Missouri River has adequate water available for the entire downstream reach to achieve regulation objectives. The four flow target locations and their flow target discharge deviation from service levels are: Sioux City (-4,000 cfs); Omaha (-4,000 cfs); Nebraska City (+2,000 cfs); and Kansas City (+6,000 cfs). A full-service level of 35,0000 cfs results in target discharges of 31,000 cfs at Sioux City and Omaha; 37,000 cfs at Nebraska City; and 41,000 cfs at Kansas City. Similarly, a minimum-service level of 29,000 cfs results in target values of 6,000 cfs less than the full-service levels at the four target locations. The relation of service levels to the volume of water in Mainstem System storage is as follows:

Date	Water in Mainstem System Storage (MAF)	Service Level (cfs)
March 15	54.5 or more*	35,000 (full-service)
March 15	31.0 to 49.0*	29,000 (minimum-service)
March 15	31.0 or less	No Service
July 1	57.0 or more*	35,000 (full-service)
July 1	50.5 or less*	29,000 (minimum-service)
* Straight-line interpolation defines intermediate service levels between full and minimum service.		

The length of the navigation season is determined by the volume of water in storage as follows:

Date	Water in Mainstem System Storage (MAF)	Season Closure Date at Mouth of Missouri River
March 15	Less than 31.0	No season
July 1	51.5 or more*	December 1 (8-month season)
July 1	41.0 to 46.8*	November 1 (7-month season)
July 1	36.5 or less*	October 1 (6-month season)
* Straight-line interpolation defines intermediate closure date between given values.		

2.2.2 Historic Flow Releases

In the navigation season, which generally runs from April 1 through November 30, releases from Gavins Point Dam are generally 25,000 to 35,000 cfs. In the winter, releases are in the 10,000 to 20,000 cfs range. In wet years with above-normal upstream inflows, releases are higher to evacuate flood control storage space in upstream reservoirs. Maximum winter releases are generally kept below 24,000 cfs to minimize downstream flooding problems caused by ice jams in the lower river. During the 1987 to 1993 and the 2000 to 2008 droughts, non-navigation releases were generally in the 8,000 to 9,000 cfs range immediately following the end and preceding the start of the navigation season. During cold weather, releases were increased up to 15,000 cfs, but generally averaged 12,000 cfs over the 3-month winter period from December through February.

2.2.3 Flow Releases for Water Quality Management

Historically, Gavins Point Dam release levels necessary to meet downstream water supply purposes exceeded the minimum release levels necessary to meet minimum downstream water quality requirements. Tentative flow requirements for satisfactory water quality were first established by the U.S. Public Health Service and presented in the 1951 Missouri Basin Inter-Agency Committee Report on Adequacy of Flows in the Missouri River. These requirements were used in flow regulation until revisions were made in 1969 by the

Federal Water Pollution Control Administration. The lower Missouri River minimum daily flow requirements for water quality (i.e., dissolved oxygen) that are given below were initially established by the Federal Water Pollution Control Administration in 1969. They were reaffirmed by the USEPA in 1974 after consideration of: 1) the current status of PL 92-500 programs for managing both point and non-point sources discharging into the river, and 2) the satisfactory adherence to the dissolved-oxygen concentration of 5.0 mg/l. The minimum daily flow requirements listed below are currently used for flow regulation purposes.

Location	Dec, Jan, Feb	Mar, Apr	May	Jun, Jul, Aug, Sep	Oct, Nov
Sioux City, IA	1,800 cfs	1,370 cfs	1,800 cfs	3,000 cfs	1,350 cfs
Omaha, NE	4,500 cfs	3,375 cfs	4,500 cfs	7,500 cfs	3,375 cfs
Kansas City, MO	5,400 cfs	4,050 cfs	5,400 cfs	9,000 cfs	4,050 cfs

Releases from Gavins Point Dam largely define the assimilative capacity and "design-flow" conditions for the lower Missouri River during periods of low flow. If water quality management requirements and flow conditions change along the lower Missouri River (e.g., more stringent water quality standards, increased point source flows, degradation of background water quality conditions, etc.), the flow released from Gavins Point Dam could potentially have a more significant impact on the ability of point source dischargers to meet water quality-based National Pollutant Discharge Elimination System (NPDES) permit limits during low-flow periods.

2.2.4 Flow Travel Times

For purposes of scheduling releases, approximate open water travel times from Gavins Point Dam are 1.5 days to Sioux City; 3 days to Omaha; 3.5 days to Nebraska City; 5.5 days to Kansas City; and 10 days to the mouth of the Missouri River near St. Louis (USACE, 2006). Table 1 provides more detailed travel times between Gavins Point Dam and USGS gage locations on the lower Missouri River under different flow conditions.

2.3 THREATENED AND ENDANGERED SPECIES CONCERNS

2.3.1 Pallid Sturgeon

Historically, the lower Missouri River was a turbid, warmwater environment with seasonally fluctuating flows. The sediment and turbidity of the water through these cycles contributed significantly to the evolution of the pallid sturgeon. The fish adapted to highly turbid and low visibility environments by physiologically evolving to enhance their ability to capture prey and avoid capture as juveniles and larvae in this low visibility environment. It is also believed that the pallid sturgeon adapted by developing spawning cues based on historical conditions in the river. The fish requires a spawning cue of suitable magnitude, duration, and timing to complete this life cycle element. It is believed that increasing flow and water temperature in the late spring is a primary factor for pallid sturgeon to initiate spawning.

Table 1. Travel times between Gavins Point Dam and USGS gage locations on the lower Missouri River.											
Travel Time in Days at 5,000 cfs (Note: Velocity in miles/day = 38.5 for GAPT and 55 for all other reaches)											
GAPT											
2.1	**SUX**										
2.8	0.7	**DENE**									
4.2	2.1	1.4	**OMA**								
5.1	3.1	2.3	1.0	**NCNE**							
6.3	4.3	3.5	2.1	1.2	**RUNE**						
7.2	5.2	4.4	3.1	2.1	0.9	**STJ**					
8.7	6.7	5.9	4.5	3.6	2.4	1.5	**MKC**				
10.	8.0	7.2	5.9	4.9	3.7	2.8	1.3	**WVMO**			
11.8	9.7	9.0	7.6	6.7	5.5	4.6	3.1	1.7	**BNMO**		
13.6	11.5	10.8	9.4	8.5	7.3	6.4	4.9	3.5	1.8	**HEMO**	
15.4	13.3	12.6	11.2	10.2	9.1	8.1	6.7	5.3	3.6	1.8	**STL**
Travel Time in Days at 13,000 cfs (Note: Velocity in miles/day = 42 for GAPT and 60 for all other reaches)											
GAPT											
1.9	**SUX**										
2.6	0.7	**DENE**									
3.8	1.9	1.3	**OMA**								
4.7	2.8	2.1	0.9	**NCNE**							
5.8	3.9	3.2	2.0	1.1	**RUNE**						
6.6	4.7	4.1	2.8	1.9	0.8	**STJ**					
8.0	6.1	5.4	4.2	3.3	2.2	1.4	**MKC**				
9.2	7.3	6.6	5.4	4.5	3.4	2.6	1.2	**WVMO**			
10.8	8.9	8.2	7.0	6.1	5.0	4.2	2.8	1.6	**BNMO**		
12.4	10.6	9.9	8.6	7.8	6.7	5.8	4.5	3.3	1.7	**HEMO**	
14.1	12.2	11.5	10.3	9.4	8.3	7.5	6.1	4.9	3.3	1.6	**STL**
Travel Time in Days at Navigation Flows (29,000-35,000 cfs) (Note: Velocity in miles/day =56 for GAPT and 80 for other reaches)											
GAPT											
1.4	**SUX**										
1.9	0.5	**DENE**									
2.9	1.5	0.9	**OMA**								
3.5	2.1	1.6	0.7	**NCNE**							
4.3	2.9	2.4	1.5	0.8	**RUNE**						
5.0	3.6	3.0	2.1	1.4	0.6	**STJ**					
6.0	4.6	4.1	3.1	2.5	1.7	1.0	**MKC**				
6.9	5.5	5.0	4.0	3.4	2.6	1.9	0.9	**WVMO**			
8.1	6.7	6.2	5.2	4.6	3.8	3.1	2.1	1.2	**BNMO**		
9.3	7.9	7.4	6.5	5.8	5.0	4.4	3.4	2.4	1.2	**HEMO**	
10.6	9.2	8.6	7.7	7.0	6.2	5.6	4.6	3.7	2.5	1.2	**STL**
Travel Time in Days at Bank-Full Flows (Note: Velocity in miles/day = 84 for GAPT and 120 for all other reaches)											
GAPT											
0.9	**SUX**										
1.3	0.3	**DENE**									
1.9	1.0	0.6	**OMA**								
2.3	1.4	1.1	0.4	**NCNE**							
2.9	2.0	1.6	1.0	0.5	**RUNE**						
3.3	2.4	2.0	1.4	1.0	0.4	**STJ**					
4.0	3.1	2.7	2.1	1.6	1.1	0.7	**MKC**				
4.6	3.7	3.3	2.7	2.3	1.7	1.3	0.6	**WVMO**			
5.4	4.5	4.1	3.5	3.1	2.5	2.1	1.4	0.8	**BNMO**		
6.2	5.3	4.9	4.3	3.9	3.3	2.9	2.2	1.6	0.8	**HEMO**	
7.0	6.1	5.8	5.1	4.7	4.2	3.7	3.1	2.4	1.6	0.8	**STL**

Note: GAPT = Gavins Point Dam (RM811); SUX = Sioux City, IA (RM732) (USGS Gage 06486000); DENE = Decatur, NE (RM691) (USGS Gage 06601200); OMA = Omaha, NE (RM616) (USGS Gage 06610000); NCNE = Nebraska City, NE (RM563) (USGS Gage 06807000); RUNE = Rulo, NE (RM498) (USGS Gage 06813500); STJ = St. Joseph, MO (RM448) (USGS Gage 06818000); MKC = Kansas City, MO (RM366) (USGS Gage 06893000); WVMO = Waverly, MO (RM293) (USGS Gage 06895500); BNMO = Boonville, MO (RM197) (USGS Gage 06909000); HEMO = Herman, MO (RM98) (USGS Gage 06934500); and STL = St. Louis, MO (RM0).

The entire lower Missouri River reach has been identified as a pallid sturgeon recovery priority area by the USFWS (USFWS, 1993). The MRRP is attempting to improve aquatic habitat diversity in the lower Missouri River by creating shallow water habitat (SWH), widening the river channel, and restoring chutes and side channels. A goal of 20-30 acres of SWH per mile by 2020 has been set. The USACE is also implementing changes to the regulation of flows from Gavins Point Dam in an attempt to enhance the pallid sturgeon population in the lower Missouri River. One such effort currently being implemented is the "Spring Pulse" where stored water is released during March and May to mimic a natural spring river level rise. It has also been suggested that a summer reduction of flows would better mimic a natural summer river level decline.

2.3.2 Interior Least Tern and Piping Plover

The BiOp's RPA for interior least tern and piping plover includes recommendations for the mechanical creation and maintenance of Emergent Sandbar Habitat (ESH) as nesting habitat for these two species in terms of habitat acres per river mile. The MNRR reach (i.e., Gavins Point Dam to Ponca , NE) was identified as a high priority reach for the two birds, and ESH goals of 40 acres per river mile by the year 2005 and 80 acres per river mile by the year 2015 have been established for this reach.

3 LOWER MISSOURI RIVER WATER QUALITY MANAGEMENT ISSUES REGARDING THE OPERATION OF USACE PROJECTS

3.1 MAINSTEM SYSTEM OPERATION – FLOW REGULATION AT GAVINS POINT DAM

In water pollution management, assimilative capacity (a.k.a., loading capacity) is used to define the amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards. It is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life. Releases from Gavins Point Dam are an important factor in determining the assimilative capacity of the lower Missouri River (i.e., higher flows provide more "dilution"). This is especially the case in the reaches of the river "immediately" downstream of Gavins Point Dam as the influence is reduced with increasing distance downstream as tributary inflows accumulate. However, during low-flow periods releases from Gavins Point Dam can represent the majority of the flow through the entire length of the lower Missouri River. Minimum flows required to ensure there is enough assimilative capacity in the Missouri River to meet dissolved oxygen requirements (i.e., State water quality standards) at selected points downstream of Gavins Point Dam are currently identified in the Missouri River Master Manual (see Section 2.2.3). These water quality management flows were identified in the late 1960's and early 1970's. If water quality management requirements and flow conditions change along the lower Missouri River (e.g., more stringent water quality standards, increased point source flows, degradation of background water quality conditions, etc.), Gavins Point Dam releases could potentially have a greater impact on water quality management. These impacts could include reducing the ability of point source dischargers to meet water quality-based National Pollutant Discharge Elimination System (NPDES) permit limits during low-flow periods (i.e., drought periods).

3.2 MISSOURI RIVER RECOVERY PROGRAM

Pursuant to the Missouri River BiOp, the Corps is constructing restoration projects to create shallow water and emergent sandbar habitat in and along the lower Missouri River. These projects are meant to enhance aquatic habitat to benefit pallid sturgeon, piping plover,

and least tern populations. Hydraulic dredging and the discharge of the dredged material to the Missouri River is the most effective and economically viable construction method for most of these restoration projects. A concern has been expressed by the State of Missouri about the potential water quality impact from the discharge of dredged material to the Missouri River during the construction of shallow water habitat projects. The concern expressed is not only in regard to water quality in the lower Missouri River, but also the potential for dredging discharges to exacerbate hypoxia concerns in the Gulf of Mexico.

4 STATE WATER QUALITY STANDARDS, SECTION 303(D) LISTINGS, AND TOTAL MAXIMUM DAILY LOADS (TMDLS)

The States of South Dakota, Nebraska, Iowa, Kansas, and Missouri have promulgated water quality standards pursuant to the Federal Clean Water Act (CWA). These state water quality standards identify beneficial uses that are to be protected, delineate specific stream segments, assign water quality-dependent beneficial uses to stream segments, and specify water quality criteria to protect the beneficial uses. As such, beneficial uses and water quality criteria have been identified by the five States for selected reaches of the lower Missouri River downstream of Gavins Point Dam.

USEPA is currently pursuing the development of numeric nutrient criteria for the Missouri River. Criteria are being considered for total nitrogen and total phosphorus. Once developed, the lower Missouri States would seemingly need to promulgate the recommended USEPA nutrient criteria, or more stringent State criteria, in their water quality standards or face USEPA promulgation of the criteria as “federal” water quality standards for the Missouri River.

Under Section 303(d) of the CWA, the five States are required to prepare a periodic list of impaired waters (i.e., Section 303(d) impaired waters list). Impaired waters refer to those waterbodies where it has been determined that technology-based effluent limitations required by Section 301 of the CWA are not stringent enough to attain and maintain applicable water quality standards. The States are required to establish and implement Total Maximum Daily Loads (TMDLs) for impaired waterbodies on their Section 303(d) lists. A TMDL specifies the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and allocates pollutant loadings among point and nonpoint sources. A TMDL is the sum of the individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background with a margin of safety. A TMDL can be generically described by the following equation:

$$TMDL = LC = \sum WLA + \sum LA + MOS$$

Where:

- LC = loading capacity or the greatest loading a waterbody can receive without exceeding water quality standards;
- WLA = wasteload allocation, or the portion of the TMDL allocated to existing or future point sources;
- LA = load allocation, or the portion of the TMDL allocated to existing or future nonpoint sources and natural background; and
- MOS = margin of safety, or an accounting of uncertainty about the relationship between pollutant loads and receiving water quality. The margin of safety can be provided implicitly through analytical assumptions or explicitly by reserving a portion of loading capacity.

4.1 SOUTH DAKOTA

South Dakota delineates one Missouri River stream segment from the Iowa border (i.e., mouth of Big Sioux River) to Big Bend Dam. This segment includes the portion of the lower Missouri River in South Dakota from the Big Sioux River to Gavins Point Dam. South Dakota's water quality standards designate the following beneficial uses for this reach of the lower Missouri River: recreation (i.e., immersion and limited-contact), warmwater permanent fish life propagation, domestic water supply, agricultural water supply (i.e., irrigation and stock watering), commerce and industrial waters, and fish and wildlife propagation. South Dakota is the only State along the lower Missouri River that has promulgated numeric water quality criteria for suspended solids. Regarding their nonpoint source pollution TMDLs, South Dakota makes the following statement regarding suspended solids:

> *Total Suspended Solids (TSS), the organic and inorganic material left on a standard glass fiber filter (0.45 micron) after a water sample is filtered through it. TSS can be used to measure the volume of solids in a waterbody. Too much suspended solids can be harmful to the biota in a stream.*

The existing TSS criteria that are applicable to the lower Missouri River in South Dakota are: 158 mg/l (daily maximum) and 90 mg/l (30-day average). These TSS criteria also apply to the major tributaries to the lower Missouri River in South Dakota (i.e., James, Vermillion, and Big Sioux Rivers).

South Dakota has not listed the lower Missouri River on the State's 303(d) list of impaired waters. The State has listed three major tributaries to the lower Missouri River as impaired (i.e., James, Vermillion, and Big Sioux Rivers). The lower James River (i.e., Yankton County line to Missouri River), lower Vermillion River (i.e., Baptist Creek to mouth), and lower Big Sioux River (i.e., Indian Creek to mouth) are all listed for TSS. The lower James and Big Sioux Rivers are also listed for fecal coliform bacteria. South Dakota has initiated TMDL assessments on the James, Vermillion, and Big Sioux Rivers, and completed TMDL development on portions of the Big Sioux River.

4.2 NEBRASKA

Nebraska's water quality standards delineate the following four stream segments along the lower Missouri River: 1) NE/SD border to Niobrara River, 2) Niobrara River to Big Sioux River, 3) Big Sioux River to Platte River, and 4) Platte River to NE/KS border. Nebraska has designated the following uses to all four segments: primary contact recreation, warmwater aquatic life, agricultural water supply, and aesthetics. It has designated the use of drinking water supply to the river downstream of the confluence of the Niobrara River, and industrial water supply to the river downstream of the confluence of the Big Sioux River. Nebraska has also designated the reach between Gavins Point Dam and Ponca State Park as an Outstanding State Resource Water for "Tier 3" protection under the State antidegradation policy. This requires that existing water quality be protected in the MNRR reach from Gavins Point Dam to Ponca State Park.

Nebraska has listed a portion of the lower Missouri River on the State's 303(d) list of impaired waters in need of TMDLs. The portion of the river downstream of the Big Sioux River is listed for Dieldrin and PCBs. This is based on fish tissue samples that found these substances at concentrations that exceeded "safe" levels defined by the State's risk assessment procedures. Based on these findings, Nebraska has issued a fish consumption advisory for the

Missouri River downstream of the Big Sioux River. The Missouri River downstream of the confluence of the Platte River is listed for *E. coli* bacteria.

The lower reaches of several major tributaries to the lower Missouri River in Nebraska have been listed as impaired waterbodies in need of TMDLs. These tributaries include: Papillion Creek, Platte River, Big Nemaha River, and Little Nemaha River. Papillion Creek is listed for *E. coli*, selenium, and fish consumption advisory (Dieldrin and PCBs). The lower Platte River is listed for *E. coli*, selenium, pH, and Atrazine. A TMDL for the lower Platte River has been developed by the State and approved by USEPA for *E. coli*. The lower Big Nemaha River is listed for *E. coli* and impaired aquatic community. TMDLs for the Big Nemaha River have been developed by Nebraska and approved by USEPA for *E. coli* and atrazine. The lower Little Nemaha River is listed for *E. coli* and fish consumption advisory (PCBs and mercury). A TMDL for the Little Nemaha River has been developed by the State and approved by USEPA for *E. coli*.

4.3 IOWA

Iowa's water quality standards' delineates one segment (IA/MO state line to the Big Sioux River) and one sub-segment (City of Council Bluffs water works intakes) along the lower Missouri River. Iowa has designated the following uses to the entire length of the Missouri River along the Iowa border: primary contact recreation (A1), warmwater wildlife and aquatic life (WW-1), and human health (HH). It has designated the use of raw water source of potable water supply (C) to the reach of the river at the Council Bluffs water works intakes.

The only reach of the Missouri River that Iowa has identified as impaired and needing a TMDL is the reach from the Boyer River to the Council Bluffs, IA water supply intake. This reach is identified as impaired due to arsenic impacts to drinking water. The Missouri River reach from the Platte River (NE) to the IA/MO state line has a TMDL in place for bacteria (NE). The entire reach of the Missouri River along the Iowa border is identified as a category 4 impaired water (impaired but a TMDL is not required) due to hydrological modification.

The lower reaches of two major tributaries, Floyd River and Soldier River, are identified as impaired due to bacteria.

4.4 KANSAS

Kansas's water quality standards identify stream segments by Hydrologic Unit Code (HUC). The Tarkio-Wolf HUC (10240005) delineates five segments on the Missouri River. The Independence-Sugar HUC (10240011) delineates 10 Missouri River segments. Kansas has designated the following uses to all the Missouri River segments: primary contact recreation, aquatic life use, special aquatic life use, domestic water supply, food procurement, industrial water supply, irrigation use, and livestock watering.

Kansas does not currently list any portions of the Missouri River as impaired. It does list the lower portion of the Kansas River as impaired due to excessive levels of total phosphorus, total suspended solids, and lead. TMDLs have been completed by Kansas and approved by USEPA on the lower Kansas River for nutrients, oxygen demand, bacteria, chlordane, and sediment. Narrative suspended solids criteria have been defined based on the "general criteria" in Kansas's water quality standards for TMDL development. The defined narrative criterion is: Suspended solids added to surface waters by artificial sources shall not interfere with the

behavior, reproduction, physical habitat or other factor related to the survival and propagation of aquatic, semi-aquatic, or terrestrial wildlife.

4.5 MISSOURI

Missouri's water quality standards delineate the following four stream segments along the lower Missouri River: 1) IA/MO border to Kansas River, 2) Kansas River to Chariton River, 3) Chariton River to Gasconade River, and 4) Gasconade River to mouth. Missouri has designated the following uses to all four segments: irrigation, livestock and wildlife watering, protection of warmwater aquatic life and human health-fish consumption, whole body contact recreation (B), secondary contact recreation, drinking water supply, and industrial.

No reach of the Missouri River is currently listed as impaired for the development of a TMDL. A TMDL was developed and is currently in place for Chlordane and PCBs for the entire length of the Missouri River in the State of Missouri. The State does list portions of the Missouri River as a category 4 impaired water (impaired but a TMDL is not required) due to channelization.

The lower reaches of the four major tributaries Blue River, Grand River, Chariton River, and Lamine River are currently listed as impaired in need of a TMDL due to bacteria. The Gasconade, Osage, and Lamine Rivers are listed as impaired due to mercury.

5 WATER POLLUTION MANAGEMENT – LOWER MISSOURI RIVER

Water pollution of the lower Missouri River can be attributed to point and nonpoint sources. Point sources generally have a greater impact during "low-flow" periods. Nonpoint sources generally have a greater impact during higher flows periods when nonpoint source pollutants are carried to the river with runoff. Point source pollution is primarily regulated through the CWA's NPDES program which regulates point sources that discharge into waters of the United States. Along the lower Missouri River, the NPDES permitting provisions are administered by the five States, with the exception that USEPA administers the NPDES program on tribal lands. Nonpoint source pollution is primarily managed under the provisions of the CWA's Section 319. Nonpoint source management is largely non-regulatory and based on voluntary actions implemented at State and Local levels.

5.1 POINT SOURCE MANAGEMENT

5.1.1 NPDES Program

The NPDES program defines municipal and industrial facilities as major dischargers based on the potential for their discharge to impact water quality. Municipal sewage treatment facilities are publicly owned treatment works (POTWs). POTWs collect domestic sewage from houses, other sanitary wastewater, and washes from commercial and industrial facilities. POTWs discharge conventional pollutants, and are covered by secondary treatment standards and State water quality standards. Major municipal dischargers include all facilities with design flows of greater than 1-million gallons per day (mgd) [*Note: 1 mgd = 1.547 cfs*]. All municipal facilities with USEPA or State approved industrial pretreatment programs are also considered a major facility. Industrial facilities generate wastewater dependent on the specific activities undertaken at a particular site, and may include manufacturing or process wastewaters, cooling waters, sanitary wastewater, and stormwater runoff. Identification of industrial facilities as major dischargers is determined based on specific ratings criteria developed by USEPA or the States.

NPDES permits can be considered a license for a facility to discharge a specified amount of a pollutant into a receiving water under certain conditions. NPDES permits can either be technology-based or water quality-based. Technology-based permits are based on Best Available Technology Economically Achievable (BAT) and Best Practicable Control Technology (BPT) for a particular discharge type or category. Water quality-based permits are based on meeting water quality standards in the waterbody receiving the discharge. Whether a point source discharge has categorical or water quality-based limits is largely dependent on the assimilative capacity of the receiving water. Design conditions for NPDES permits are based on statistically determined “low-flow” and background water quality conditions which are used to define the assimilative capacity of the receiving water under the design conditions. Based on the design conditions, the amount of a pollutant that can be discharged and still meet water quality standards at an appropriate point, given allowances for zones of initial dilution and mixing, below the discharge point is determined. Design flows that are commonly used for receiving waters when establishing NPDES permit limits are 1Q10 (compliance with acute water quality criteria), 7Q10 (compliance with chronic water quality criteria), and 30Q5 (compliance with chronic ammonia water quality criteria).

The design flow conditions for the lower Missouri River, especially the upper reaches, have been largely defined by the past regulation of flows from Gavins Point Dam. Any significant changes to the regulation of flows from Gavins Point Dam could have an impact on water quality-based permitting of point source dischargers to the lower Missouri River, including powerplants, municipal wastewater treatment plants, and industrial facilities. USEPA is currently proposing changes to water quality standards regarding ammonia that could result in a significant reduction in numeric ammonia criteria. If these proposed changes were to occur it could increase the number of facilities that would require water quality-based permits for ammonia, and reduce ammonia limits in existing water quality-based permits.

5.1.2 Major Facilities, Design Flows, and Water Quality-Based Permits on the Lower Missouri River

5.1.2.1 South Dakota

Major facilities identified by the State of South Dakota that discharge directly to the Missouri River or to a tributary within 10 miles of the Missouri River are listed in Table 2.

Table 2. Major facilities in South Dakota that discharge directly to the Missouri River or to a tributary within 10 miles of the river.

Facility Name*	Facility Type	Facility Category	Facility Location**	NPDES Number	Facility Design Flow (mgd)	Permit Limits***
Yankton WWTP	Municipal	Sewage Trt. Plant	RM805	SD0023396	4.9	WQ[2]
Vermillion WWTP	Municipal	Sewage Trt. Plant	RM772[1]	SD0020061	2.0	WQ[1]

* WWTP = Waste Water Treatment Plant.

** (1) The Vermillion WWTP discharges to the Vermillion River within 10 miles of the Missouri River. RM772 is the confluence of the Vermillion River with the Missouri River.

*** Water quality-based limits are in addition to WWTP categorical limits for $CBOD_5$, total suspended solids, and pH.
(1) Total residual chlorine, fecal coliform, total coliform, oil and grease, dissolved oxygen, and acute toxicity.
(2) Total residual chlorine, fecal coliform, total coliform, petroleum hydrocarbons, oil and grease, and acute toxicity.

5.1.2.2 Nebraska

Major facilities identified by the State of Nebraska that discharge directly to the Missouri River or to a tributary within 10 miles of the Missouri River are listed in Table 3.

Table 3. Major facilities in Nebraska that discharge directly to the Missouri River or to a tributary within 10 miles of the river.

Facility Name*	Facility Type	Facility Category**	Facility Location	NPDES Number	Facility Design Flow (mgd)	Permit Limits***
Tyson Fresh Meats (Dakota City)	Industrial	Meat Packing	RM726	NE0001392	4.9	Categorical
Blair WWTP	Municipal	Sewage Trt. Plant	RM647	NE0036307	2.0	WQ(1)
OPPD Fort Calhoun Station	Industrial	Power Plant (Nuclear)	RM646	NE0000418	529	WQ(2)
OPPD North Omaha Station	Industrial	Power Plant (Coal)	RM625	NE0000621	493	WQ(2)
Omaha Missouri River WWTP	Municipal	Sewage Trt. Plant	RM612	NE0036358	41	WQ(3)
Bellevue WWTP	Municipal	Sewage Trt. Plant	RM601	NE0036307	1.9	WQ(1)
Omaha Papillion Creek WWTP	Municipal	Sewage Trt. Plant	RM596	NE0112810	90	WQ(3)
Omaha Combined Sewer Overflow	Municipal	CSO	RM596	NE0133680	-----	WQ(4)
Plattsmouth WWTP	Municipal	POTW/CSO	RM591	NE0021121	2.0	WQ(1)
Nebraska City WWTP	Municipal	Sewage Trt. Plant	RM562	NE0021245	1.1	WQ(1)
OPPD Nebraska City Station	Industrial	Power Plant (Coal)	RM556	NE0021245	530	WQ(2)
NPPD Cooper Brownville Station	Industrial	Power Plant (Nuclear)	RM532	NE0001244	625	WQ(2)

* WWTP = Waste Water Treatment Plant

** CSO = Combined Sewer Overflow

*** Meat packing categorical limits include: BOD_5, total suspended solids, oil and grease, pH, ammonia, total nitrogen, *E. coli*, fecal coliform, total residual chlorine, acute toxicity, and chromium.
Water quality-based limits are in addition to WWTF categorical limits for $CBOD_5$, total suspended solids, and pH.
(1) Total residual chlorine and *E. coli.*
(2) Temperature and total residual chlorine.
(3) Ammonia, total residual chlorine, acute toxicity, and *E. coli.*
(4) *E. coli.*

Design flows currently utilized by the Nebraska Department of Environmental Quality (NDEQ) to assess water quality-based permitting requirements for point source discharges to the lower Missouri River are given in Table 4.

In Nebraska, all NPDES permitted dischargers are evaluated for the need to establish water quality-based limits. Dischargers with reasonable potential to exceed water quality standards under design conditions and allowances for mixing zones are given water quality-based limits. Water quality criteria for some point source constituents (i.e., *E. coli*) are required to be met at the “end-of-pipe” and the reasonable potential test is not applicable. The two Omaha wastewater treatment facilities currently have water quality-based NPDES permit limits for ammonia, total residual chlorine, and *E. coli*. The CSO (i.e., combined sewer overflow) permit currently being developed for Omaha will also be water quality-based for *E. coli*. All the Nebraska power plants that withdraw water for cooling and then discharge it back to the Missouri River have water quality-based NPDES limits for temperature (i.e., OPPD Fort Calhoun Station, OPPD North Omaha Station, OPPD Nebraska City Station, and NPPD Cooper-Brownville Station). At this point the smaller cities (i.e., Blair, Bellevue, Plattsmouth, and Nebraska City) don’t meet the reasonable potential test and have categorical limits. A reduction in the Missouri River design flows could alter the results of the reasonable potential test for these smaller cities. The Tyson “meat-packing” facility in Dakota City had water quality-based ammonia limits established until the USEPA recently established categorical limits on ammonia for meat packers that were more stringent than the previous water quality-based limits.

Table 4. Design flows for the lower Missouri River currently utilized by the Nebraska Department of Environmental Quality for the development of water quality-based NPDES permits.

Flow Condition	Missouri River @ Yankton 1976-1995 (cfs)	Missouri River @ Sioux City 1989-2008 (cfs)	Missouri River @ Decatur 1989-2008 (cfs)	Missouri River @ Omaha 1989-2008 (cfs)	Missouri River @ Nebraska City 1989-2008 (cfs)	Missouri River @ Rulo 1989-2008 (cfs)
Spring (Mar-May)						
1q10	6,613	9,011	9,730	11,646	15,984	16,904
7q10	7,390	9,638	10,218	12,284	17,140	18,243
30q5	13,378	15,076	15,479	18,257	24,142	26,016
Summer (Jun-Oct)						
1q10	8,132	10,999	12,228	15,205	18,617	20,068
7q10	11,098	12,577	13,638	16,222	19,771	21,143
30q5	20,656	19,987	21,003	24,010	27,001	28,428
Winter (Nov-Feb)						
1q10	8,568	6,568	8,556	8,619	8,815	10,161
7q10	9,288	9,624	10,367	11,405	11,907	12,822
30q5	11,579	11,452	12,138	13,971	17,027	18,055
Navigation (Apr-Nov)						
1q10	6,890	9,008	9,881	11,606	13,999	15,420
7q10	7,930	9,312	10,021	11,917	14,779	16,158
30q5	12,165	12,693	13,523	16,134	19,938	21,468
Non-Navigation (Dec-Mar)						
1q10	6,594	6,615	8,507	8,668	8,893	10,225
7q10	7,967	10,018	10,591	11,453	12,133	12,972
30q5	11,481	12,061	12,625	14,505	17,770	18,775

(Source: Nebraska Department of Environmental Quality, 2009)

5.1.2.3 Iowa

Major facilities identified by the State of Iowa that discharge directly to the Missouri River or to a tributary within 10 miles of the Missouri River are listed in Table 5.

5.1.2.4 Kansas

Major facilities identified by the State of Kansas that discharge directly to the Missouri River or to a tributary within 10 miles of the Missouri River are listed in Table 6.

5.1.2.5 Missouri

Major facilities identified by the State of Missouri that discharge directly to the Missouri River or to a tributary within 10 miles of the Missouri River are listed in Table 7.

Table 5. Major facilities in Iowa that discharge directly to the Missouri River or to a tributary within 10 miles of the river.

Facility Name*	Facility Type	Facility Category**	Facility Location	NPDES Number	Facility Design Flow (mgd)***	Permit Limits****
Sioux City WWTP	Municipal	Sewage Trt. Plant/CSO	RM729	9778001	30/13	WQ(1)
Terra Industries – Port Neal (Sergeant Bluffs)	Industrial	Nitrogenous Fertilizers	RM723	9700104	<1	Categorical
Midamerican Energy – Neal North	Industrial	Power Plant (Coal)	RM718	9700102	720	WQ(2)
Midamerican Energy – Neal South	Industrial	Power Plant (Coal)	RM716	9700106	483	WQ(3)
Midamerican Energy – Council Bluffs	Industrial	Power Plant (Coal)	RM606	7820101	560	WQ(5)
Council Bluffs WWTP	Municipal	Sewage Trt. Plant/CSO	RM605	7820001	12/6.5	WQ(4)
GMU WWTF (Glenwood)	Municipal	Sewage Trt. Plant/CSO	RM591	6525001	1.4/1.2	WQ(6)

* WWTP = Waste Water Treatment Plant.
** CSO = Combined Sewer Overflow.
*** First value is average wet weather flow and second value is average dry weather flow.
**** Categorical limits include: Ammonia, organic nitrogen, nitrate nitrogen, oil and grease, pH, and acute toxicity. Water quality-based limits are in addition to POTW categorical limits for $CBOD_5$, total suspended solids, and pH.
(1) Ammonia, total residual chlorine, fecal coliform, and acute toxicity.
(2) Acute toxicity.
(3) Total residual chlorine and temperature.
(4) Total residual chlorine, *E. coli*, and acute toxicity.
(5) Total iron.
(6) Fecal coliform and acute toxicity.

Table 6. Major facilities in Kansas that discharge directly to the Missouri River or to a tributary within 10 miles of the river.

Facility Name*	Facility Type	Facility Category**	Facility Location	NPDES Number	Facility Design Flow (mgd)	Permit Limits*
City of Atchison	Municipal	Sewage Trt. Plant	RM421	KS0085600	1.4	
MGP Ingredients, Inc.	Industrial	Industrial	RM421	KS0026158	5	
City of Leavenworth	Municipal	Sewage Trt. Plant	RM396	KS0099201	6.9	
City of Lansing	Municipal	Sewage Trt. Plant	RM388	KS0038563	2.8	
KBPU Nearman Creek Station	Industrial	Power Plant	RM379	KS0119075	210	
KBPU Quindaro Station	Industrial	Power Plant	RM374	KS0080942	280	
Kansas City Plant # 1 WWTP	Municipal	Sewage Trt. Plant	RM368	KS0118231	28	
City of Bonner Springs	Municipal	Sewage Trt. Plant	RM368	KS0082881	1.4	
Kansas City (Plant #20) WWTP	Municipal	Sewage Trt. Plant	RM368	KS0080195	7	
JOCO Nelson Complex WWTP	Municipal	Sewage Trt. Plant	RM368	KS0055492	15	
JOCO Mill Creek Regional WTF	Municipal	Sewage Trt. Plant	RM368	KS0088269	18.8	
JOCO Blue River District # 1	Municipal	Sewage Trt. Plant	RM358	KS0092738	10.5	
JOCO Tomahawk Cr. MSD # 1 WWTP	Municipal	Sewage Trt. Plant	RM358	KS0055484	10	
JOCO Douglas Smith Middle Basin WWTP	Municipal	Sewage Trt. Plant	RM358	KS0119601	14.5	

* Information not provided as of yet.

Table 7. Major facilities in Missouri that discharge directly to the Missouri River or to a tributary within 10 miles of the river.

Facility Name*	Facility Type	Facility Category**	Facility Location	NPDES Number	Facility Design Flow (mgd)	Permit Limits***
St. Joseph	Municipal	Sewage Trt. Plant/CSO	RM451	MO0023043	27	WQ (1)
KCPL (Aquila) Lake Road Plant	Industrial	Power Plant (Coal)	RM446	MO0004898	114	WQ (2)
KCPL Iatan Generating Station	Industrial	Power Plant (Coal)	RM411	MO0082996	472	WQ (2)
Kansas City Westside WWTP	Municipal	Sewage Trt. Plant	RM367	MO0024929	23	WQ (3)
Trigen-KC Grand Avenue Station	Industrial	Power Plant (Coal)	RM360	MO0004847	154	WQ (2)
KC, Blue River WWTF	Municipal	Sewage Trt. Plant/CSO	RM358	MO0024911	105	WQ (3)
Birmingham WWTF	Municipal	Sewage Trt. Plant	RM357	MO0049531	20	WQ (4)
Independence, Rock Cr. WWTF	Municipal	Sewage Trt. Plant/CSO	RM357	MO0089681	10	WQ (4)
KCPL Hawthorne Station	Industrial	Power Plant (Coal)	RM356	MO0004855	602	WQ (2)
Independence Elec. Atherton Plant	Industrial	Power Plant (Coal)	RM349	MO0101087	40	WQ (2)
KCPL Sibley Station	Industrial	Power Plant (Coal)	RM336	MO0004871	458	WQ (2)
Boonville WWTP	Municipal	Sewage Trt. Plant/CSO	RM195	MO0040738	1.5	WQ (5)
Columbia Regional WWTP	Municipal	Sewage Trt. Plant	RM175	MO0097837	21	WQ (6)
Jefferson City WWTP	Municipal	Sewage Trt. Plant	RM136	MO0094846	11	WQ (4)
Ameren UE, Callaway PP	Industrial	Power Plant (nuclear)	RM115	MO0098001	69	WQ (8)
Ameren UE, Labadie PP	Industrial	Power Plant	RM57	MO0004812	1,486	WQ (2)
DCSD, Treatment Plant #2	Municipal	Sewage Trt. Plant	RM44	MO0116572	7	WQ (4)
DCSD, Treatment Plant #1	Municipal	Sewage Trt. Plant	RM33	MO0085472	5	WQ (4)
MSD, Missouri River WWTF	Municipal	Sewage Trt. Plant	RM30	MO0004391	28	WQ (4)
St. Charles Mo. River WWTF	Municipal	Sewage Trt. Plant	RM27	MO0058351	5	WQ (4)

* WWTP = Waste Water Treatment Plant.

** CSO = Combined Sewer Overflow.

*** Categorical limits include: Ammonia, organic nitrogen, nitrate nitrogen, oil and grease, pH, and acute toxicity. Water quality-based limits include CBOD, total suspended solids, pH, and oil and grease. Additional requirements may include:
(1) Total recoverable cadmium, dissolved chromium, and total recoverable copper
(2) Temperature.
(3) Cyanide and ammonia as nitrogen.
(4) Fecal coliform.
(5) Total recoverable chromium, copper, lead, nickel, and zinc.
(6) Total recoverable arsenic, copper, cadmium, mercury, and total chromium, silver, cyanide, lead, nickel, and zinc.
(7) Residual chlorine.

Missouri's water quality standards require that the water temperature of the Missouri River not be raised by more 5°F or exceed a 90°F temperature cap in the summer months at the end of the regulatory mixing zone (defined as 25% of the 7Q10 flow). The USEPA recently reviewed the Missouri NPDES permitting program and concluded that during heat events in the hot summers of the past few years, virtually all of the big river power plant plants are contributing to violations of Missouri water quality standards (USEPA, 2007). The violations are due to river temperatures that approach or even exceed the temperature cap on heat. USEPA recommends that Missouri's NPDES permits should contain limits that reflect the heat cap and include monitoring to detail the pattern of the exceedences. They also recommend, in some cases, 316(a) studies and/or reviews should be initiated.

USEPA's 2007 review of Missouri's NPDES program regarding 316(a) regulations controlling heat discharges at power plants stated the following (USEPA, 2007):

> *"As river background temperatures approach the water quality standard, the wasteload allocation for heat approaches zero. If Missouri issues permits which protect the heat cap, then it is certain that there will be periodic violations of these permits."*
>
> *"Since 1999, the Missouri River has shown higher temperatures than those recorded over the previous century or so of observations. These 'heat events', which last for several days, occur in the height of the summer, in late July and early August, and have been related to the intense drought in the Upper Missouri River watershed."*
>
> *"For power plants cooled with river water, these heat events create a worst case scenario. The slow, low flows of the river minimize dissipation of the heat. The electrical demands of air conditioners push the plants to full capacity. These plants, needing maximum cooling, must do so by pumping through hot river water. As the intake water grows hotter, there is a loss of cooling efficiency and the plants overall electrical output can decline. Exceedences of the water quality standard temperature cap are seen as the heated discharge water mixes with the river."*
>
> *Review of permits for plants on the Missouri River show that several plants discharge heat in excess of the requirements set by Missouri's water quality standards. Both the KCPL facility in Kansas City and the Ameren-Labadie facility near St. Louis discharge amounts of heat that would warm more than 25% of the river above the 5°F during low river flows. Virtually all Missouri River power plants are impacted by high river temperatures during hot summers."*
>
> *"The Clean Water Act allows for less stringent permit limits if there is a demonstration that the permit limits <u>will assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on that body of water</u>. While 316(a) studies were done for all the power plants using once through cooling, changing river conditions and expansions of generation capacity would suggest that those original 316(a) studies should be reviewed, and possibly supplemented with new work to assure that the rivers are not being adversely impacted."*

5.1.2.6 Location of Major Point Source Dischargers along the Lower Missouri River

Attachment 1 depicts the locations of major point source discharges along the lower Missouri River.

5.2 NONPOINT SOURCE MANAGEMENT

Selected reaches of the lower Missouri River and tributaries to the river have been identified as impaired due to nonpoint source pollution. TMDLs have been developed or are being developed to address the identified water quality impairment and manage nonpoint source pollution.

5.2.1.1 South Dakota

5.2.1.1.1 Lower James River Watershed

The long-term goal of the Lower James River Watershed Assessment is to locate and document sources of nonpoint source pollution in the watershed and produce feasible restoration recommendations. The assessment will provide information needed to develop a watershed implementation work plan with the objective of decreasing erosion, sedimentation, and fecal coliform loadings in the James River and tributary streams in the watershed. The assessment will result in a TMDL report for the 303(d) listed waterbodies in the James River watershed downstream of the Beadle/Sanborn county line. The parameters of concern in the river and stream segments are suspended solids and fecal coliform bacteria.

The Lower James River Watershed Assessment includes drainage from approximately 16 counties in southeastern South Dakota. The watershed is approximately 2.5 million acres (10,350 km^2). The assessment is intended to be the initial phase of a watershed-wide restoration project. Through water quality monitoring, stream gaging, stream channel analysis, and land use analysis, the sources of impairments to the streams and the watershed will be documented and feasible alternatives for restoration will be identified in a final project report.

5.2.1.1.2 Vermillion River Watershed

The long-term goal of the Vermillion River Basin Watershed Assessment is to locate and document sources of nonpoint source pollution in the watershed and produce feasible restoration recommendations. The assessment will provide information needed to develop a watershed implementation work plan with the objective of decreasing erosion, sedimentation, and fecal coliform loadings in the river and tributary streams in the project area. This assessment will result in a TMDL report for the 303(d) listed segments of the Vermillion River downstream of Lake Thompson. The parameters of concern in the river and stream segments are suspended solids and fecal coliform bacteria.

The Vermillion River Watershed Assessment includes drainage from approximately 9 counties in southeastern South Dakota. The watershed is approximately 1.43 million acres (5,787 km^2). The assessment is intended to be the initial phase of a watershed-wide restoration project. Through water quality monitoring, stream gaging, stream channel analysis, and land use analysis, the sources of impairments to the river and the watershed will be documented and feasible alternatives for restoration will be identified in a final project report.

5.2.1.1.3 Big Sioux River Watershed Project

The Big Sioux Watershed Project is a 10-year implementation strategy addressing the TMDLs which resulted from the assessment studies along the north-central and central Big Sioux River watersheds. The project will restore and/or maintain the water quality of the Big Sioux River and it's tributaries to meet designated beneficial uses. Stream assessments completed by the East Dakota Water Development District (EDWDD) covering the north-central and central portions of the Big Sioux River mainstem and tributaries from Watertown to the north and Brandon to the south found impairment of designated uses from suspended solids and fecal coliform bacteria. This project will use a variety of best management practices (BMPs) to address the impairments. Activities to reduce current sediment and bacteria loadings will target sub-watersheds within the project area. An information and education campaign will be conducted to keep the public informed on project progress and to provide information on

BMPs and water quality. An advisory ranking committee comprised of one representative from each participating conservation district and the EDWDD will prioritize BMPs submitted for funding.

5.2.1.2 Nebraska

TMDLs for *E. coli* bacteria have been developed for the lower reaches of Papillion Creek, Platte River, Little Nemaha River, and Big Nemaha River which flow directly into the Missouri River. A TMDL has also been developed for Atrazine for the lower reach of the Big Nemaha River. Implementation of the reductions for *E. coli* will be carried out through a combination of regulatory and non-regulatory activities. Point sources will be regulated under the auspices of the NPDES and the Rules and Regulations Pertaining to Livestock Waste Control. Nonpoint source pollution will be addressed using available programs, technical advice, information and education and financial incentives such as cost share. A coalition of local agencies is currently developing an implementation plan to manage stormwater runoff in the Papillion Creek watershed.

5.2.1.3 Iowa

A TMDL for the Big Sioux River has been developed for pathogen indicators. An implementation plan to address the TMDL has not be developed, but analysis of the watershed indicates that controlling livestock manure runoff and cattle in streams would need to be a large part of a plan to reduce bacteria loadings.

5.2.1.4 Kansas

The State of Kansas has developed TMDLs for nonpoint source related pollutants for the lower Kansas River. The pollutants for which TMDLs have been developed are chlordane, *E. coli* bacteria, sediment/total suspended solids, nutrients/oxygen demand on aquatic life. Development of a TMDL implementation plan for *E. coli* bacteria has been identified as a high priority.

5.2.1.5 Missouri

Table 8 summarizes the nonpoint source related TMDLs and watershed management plans developed by the State of Missouri for the Missouri River and its major tributaries.

6 CURRENT WATER QUALITY MONITORING OF THE LOWER MISSOURI RIVER

6.1 U. S. ARMY CORPS OF ENGINEERS

6.1.1 Omaha District

6.1.1.1 Gavins Point Dam Releases

At all six of the Missouri River mainstem dams and powerplants, “raw water” is drawn off the penstocks or intake structure and piped through the powerplant as a “raw water” supply line that is tapped for various uses in the powerplant (e.g., cooling water, etc.). The “raw water” supply line is an open-ended, flow-through system with the water wasted to the dam tailwaters. As a measure of the water quality conditions of the six mainstem dam releases, the Omaha District regularly monitors the water quality conditions of water in the “raw water” supply lines.

Table 8. Summary of nonpoint source related TMDLs and watershed management plans developed in Missouri for the Missouri River and its major tributaries.

Basin Name	8-Digit HUC No.	Stream/River	TMDLs	Watershed Mgmt. Plan*
Missouri River Bottom	10240001	Missouri River	Chlordane, PCBs	None
Nishnabotna River	10240004	Nishnabotna River	None	None
Tarkio-Squaw Tributaries	10240005	Missouri River	Chlordane, PCBs	None
Nodaway River	10240010	Nodaway River	None	None
Missouri River Bottom	10240011	Missouri River	Chlordane, PCBs	None
Platte River	10240012	Platte River	None	None
Kansas River	10270104	Kansas River	None	None
Lower Grand River	10280103	Grand River	None	None
Lower Chariton	10280202	Chariton River	None	None
Lower Osage River	10290111	Osage River	Mercury	None
Lower Gasconade River	10290203	Gasconade River	Mercury	None
Missouri River Mainstem – Kansas City to Glasgow	10300101	Blue River	Chlordane	NRCS Rapid Watershed Assessment includes planning for entire HUC 8
		Missouri River	Chlordane, PCBs	
Missouri River Mainstem – Glasgow to Hermann	10300102	Missouri River	Chlordane, PCBs	None
Lamine River	10300103	Lamine River	Mercury	None
Missouri River Mainstem – Hermann to St. Louis	10300200	Missouri River	Chlordane and PCBs	None

* Watershed management plans for identified stream/river. Management plans may be in place in the basin for tributaries to the identified stream/river.

(Source: "The Missouri Nonpoint Source Management Program Annual Report for Federal Fiscal Year 2008", Missouri Department of Natural Resources.)

Water is drawn from the "raw water" supply lines and piped to a "sampling chamber" where water quality conditions (i.e., temperature, dissolved oxygen, and conductivity) are measured hourly and recorded. Monthly "grab" samples are collected at the "sampling chamber" year-round and analyzed for various parameters (i.e., physical, nutrient, inorganic, and organic constituents). Monitoring the water quality conditions of the "raw water" supply line in the powerplant facilitates year-round sampling, and the monitored water quality conditions are believed representative of the dam releases and the water quality conditions present in the tailwaters (i.e., Missouri River) immediately downstream of the dams.

The "raw water" supply line intake at Gavins Point dam draws water from Lewis and Clark Lake at elevation 1176.7 feet-msl; approximately 30 feet below the reservoir surface and 42 above the reservoir bottom. The "raw water" piped to the water quality "sampling chamber" in the Gavins Point powerplant passes through the intake structure, enters a 14-inch raw water header pipe and travels 50 feet. The water then enters a 1-inch PVC pipe and travels an additional 70 feet to the "sampling chamber" where water quality conditions are monitored.

6.1.1.2 Ambient Missouri River Water Quality Conditions

Since 2003, the Omaha District has cooperated with the State of Nebraska (NDEQ), through an Inter-Agency Support Agreement, to monitor ambient water quality conditions of the lower Missouri River along the Nebraska border. To date, the water quality data collected from this effort has been used by the Omaha District to prepare water quality reports, and by the NDEQ to meet Federal CWA water quality monitoring, assessment, and reporting requirements. Monitoring site locations and parameter coverage were largely identified by the NDEQ to meet their requirements pursuant to the Federal CWA. Fixed-station monitoring has occurred at the following seven sites on the lower Missouri River: Gavins Point Dam tailwaters (RM811); near Maskell, NE (RM774); near Ponca, NE (RM753); at Decatur, NE (RM691); at Omaha, NE (RM619); at Nebraska City, NE (RM563); and at Rulo, NE (RM498). Water quality monitoring consisted of year-round collection of monthly near-surface grab samples (i.e., non-isokinetic samples). The grab samples were collected in the river thalweg or from the riverbank in an area of fast current. The collected grab samples were analyzed for numerous parameters (i.e., physical, nutrient, inorganic, organic, and biological constituents). Field measurements taken at the time of sample collection included temperature, pH, dissolved oxygen, conductivity, ORP, and turbidity.

6.1.1.3 Sediment Sampling and Elutriate Testing at Proposed MRRP Project Sites

Past construction of shallow water and emergent sandbar habitat at MRRP project sites on the lower Missouri River has involved dredging and the discharge of dredged materials to the Missouri River. The dredging and discharge of dredged materials to the river during construction activities necessitated the requirements for an individual Section 404 permit to be met. To meet the Section 404 Individual Permit requirements, a Section 401 Certification must be obtained from the appropriate States that “certifies” that the proposed actions will not “violate” State water quality standards. To facilitate review of past MRRP projects in the Omaha District for Section 401 Certification, sediment sampling and “elutriate testing” of material from the proposed dredging sites has been conducted. The “elutriate testing” of the collected sediment samples was done in accordance with the Inland Testing Manual, “Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual (USEPA and USACE, 1998).

6.1.2 Kansas City District

6.1.2.1 Ambient Missouri River and Tributary Water Quality Conditions

Since 2009, the Kansas City District has monitored ambient water quality conditions of the lower Missouri River and its major tributaries. To date, the water quality data collected from this effort has been used by the Kansas City District to conduct water quality assessments to support implementation of the MRRP. Fixed-station monitoring has occurred at the following five sites on the lower Missouri River: at Atchison, KS (RM423); at Sibley, MO (RM336); at Waverly, MO (RM293); at Glasgow, MO (RM226), and at Hermann, MO (RM98). Fixed-station monitoring has occurred on the lower reaches of the following major tributaries: James River, SD; Vermillion River, SD; Big Sioux River, SD/IA; Little Sioux River, IA; Platte River, NE; Nishnabotna River, IA; Tarkio River, MO; Big Nemaha River, NE; Platte River, MO; Fishing River, MO; Crooked River, MO; Grand River, MO; Chariton River, MO; Lamine River, MO; Loutre River, MO; and Gasconade River, MO. Water quality monitoring consisted of year-round collection of monthly near-surface grab samples (i.e., non-isokinetic samples). The grab samples were collected in the river thalweg or from the riverbank in an area of fast current. The

collected grab samples were analyzed for numerous parameters (i.e., physical, nutrient, inorganic, organic, and biological constituents). Field measurements taken at the time of sample collection included temperature, pH, dissolved oxygen, conductivity, and turbidity.

6.1.2.2 Sediment Sampling and Elutriate Testing at Proposed MRRP Project Sites

Past construction of shallow water and emergent sandbar habitat at MRRP project sites on the lower Missouri River has involved dredging and the discharge of dredged materials to the Missouri River. The dredging and discharge of dredged materials to the river during construction activities necessitated the requirements for an individual Section 404 permit to be met. To meet the Section 404 Individual Permit requirements, a Section 401 Certification must be obtained from the appropriate States that “certifies” that the proposed actions will not “violate” State water quality standards. To facilitate review of past MRRP projects in the Kansas City District for Section 401 Certification, sediment sampling and “elutriate testing” of material from the proposed dredging sites has been conducted. The “elutriate testing” of the collected sediment samples was done in accordance with the Inland Testing Manual, “Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual (USEPA and USACE, 1998).

6.1.2.3 Monitoring at Constructed MRRP Project Sites

In 2009, the Kansas City District began monitoring water quality conditions at selected constructed habitat sites created to support the MRRP. This data has been used to support the MRRP and determine if differences exist between the mainstem and created habitats. Sampling has been conducted at California Bend (2 sites, RM 650), Tobacco Island (RM 590), Upper Hamburg Bend (RM 556), Lisbon Bottoms (RM 218), and Overton Bottoms (RM 187). Water quality monitoring consisted of year-round collection of near-surface samples (i.e., non-isokinetic samples). Six samples were taken per site. Three samples were collected from equal intervals laterally across the mainstem of the river and three samples were taken from equal intervals longitudinally through the created habitat. The collected grab samples were analyzed for numerous parameters (i.e., physical, nutrient, inorganic, organic, and biological constituents). Field measurements taken at the time of sample collection included temperature, pH, dissolved oxygen, conductivity, and turbidity.

6.2 U.S. GEOLOGICAL SURVEY

6.2.1 NASQAN Program

The U.S. Geological Survey (USGS) has been implementing the National Stream Quality Accounting Network (NASQAN) program since 1973. The latest design for the NASQAN program was implemented in October 2007. Under this design, the goal of the NASQAN program is to report on the concentrations and loads of selected constituents delivered by major rivers to priority coastal waters and inland sub-basins. These priority basins have significant management interest in reducing delivery of constituents that contribute to adverse conditions in receiving waters. Collected information will be used to: 1) determine sources and relative yields of constituents within priority basins, 2) identify climate change impacts, and 3) describe long-term trends in the loads and concentrations of selected constituents at key locations.

The current NASQAN program identifies two primary objectives. One objective is to address questions about the annual transport of selected constituents from selected large rivers to coastal waters of the United States. These questions include:

- What are the concentrations and loads of nitrogen, phosphorus, carbon, silica, dissolved solids, selected pesticides, and suspended sediment discharging to coastal waters of the United States?
- How do concentrations and loads of these constituents change through time?

The second primary objective is to address questions specific to the Mississippi-Atchafalaya River Basin related to hypoxia in the Gulf of Mexico. These questions include:

- What are the seasonal loads of total and dissolved nutrients from the Mississippi River Basin to the Gulf of Mexico?
- What are the concentrations and loads of the identified constituents in major sub-basins and selected smaller basins within the Mississippi River Basin?
- How do concentrations and loads of the identified constituents change through time in major sub-basins and selected smaller basins within the Mississippi River Basin?

Four station locations are identified for monitoring in the lower Missouri River Basin under the current NASQAN program. Three of the monitoring stations are located on the Missouri River: Missouri River at Yankton, SD (06467500), Missouri River at Council Bluffs, IA (06610505), and Missouri River at Hermann, MO (06934500). However, the site at Yankton, SD was discontinued in October, 2009, due to loss of cooperator funding from the USACE. The fourth NASQAN monitoring station in the lower Missouri River Basin is located on a major tributary to the Missouri River. The site is on the lower reaches of the Platte River at Louisville, NE (06805500). The Platte River site is also part of USGS's National Water-Quality Assessment (NAWQA) program.

Methods of sample collection used by the NASQAN program conform to the "USGS National Field Manual for the Collection of Water-Quality Data". To account for spatial variability in river water quality conditions, current NASQAN water sample collection utilizes isokinetic, depth-integrated and width-discrete sampling techniques that provide samples representative of stream conditions. The spatial variability of a constituent in a stream/river cross-section is dependent upon a number of factors. If the constituent is in the dissolved phase its distribution in the stream cross-section depends on how well mixed the stream is and where the source of entry to the stream of the constituent is located. If the constituent is associated with the particulate phase, then in addition to the factors affecting constituents in the dissolved phase there is also the vertical distribution due to sinking of the particulate matter. This has implications for the calculation of flux (the mass of the constituent transported by the river in a given amount of time). If the constituent concentration changes in the stream either horizontally or vertically or both, then where and how the sample is collected will affect the concentration used to calculate the flux. Isokinetic depth-integrated samplers accumulate a representative water sample continuously and isokinetically, that is, stream water approaching and entering the sampler intake does not change in velocity, from a vertical section of a stream while transecting the vertical at a uniform rate. At the Missouri River NASQAN sites 3 to 5 equal-discharge-increments (EDI) are sampled across the river channel. Historically, the isokinetic, depth-integrated EDI samples were either composited and analyzed or analyzed separately and mathematically combined. Current methods are to analyze 4 isokinetic, depth-integrated EDI samples separately and then to mathematically combine the results into a "composite" value. Water quality parameters measured in the NASQAN program include physical, nutrient, inorganic, organic, microbiological, biological, organic, and sediment constituents. Attachment 2 lists the individual constituents measured under the NASQAN program.

6.2.2 Real-Time Water Quality Monitoring

USGS maintains real-time water quality monitoring equipment at selected USGS gaging stations along the lower Missouri River. Table 9 lists locations and water quality parameters for which real-time monitoring results are available as of October, 2009.

Table 9. USGS monitoring stations along the lower Missouri River where real-time water quality monitoring is ongoing as of October, 2009.

Station Location	River Mile	USGS Gage No.	Water Quality Parameters Available*
Missouri River near Ponca, NE	753	06479097	W, S, D, T
Missouri River at Sioux City, IA	732	06486000	W
Missouri River at Decatur, NE	691	06601200	W
Missouri River at Omaha, NE	616	06610000	W
Missouri River at Council Bluffs, IA	607	06610505	W, S, D
Missouri River at Nebraska City, NE	563	06807000	W
Missouri River at Waverly, MO	293	06895500	W, S, D, T
Missouri River at Boonville, MO	197	06909000	W, S, D, T

* W = Water Temperature, S = Specific Conductance, D = Dissolved Oxygen, and T = Turbidity.

6.2.3 Sediment Monitoring Program

USGS, in cooperation with the USACE, monitors sediment at selected locations along the lower Missouri River. The major purpose of the sediment monitoring program is to calculate daily loads. Missouri River sites monitored under the sediment monitoring program include: Sioux City, IA (~40 samples per year); Omaha, NE (~80 samples per year); Nebraska City, NE (~80 samples per year); St. Joseph, MO (~40 samples per year); Kansas City, MO (~40 samples per year); and Hermann, MO (~40 samples per year). Water-column samples are collected using the same techniques utilized for collecting NASQAN samples. Bed samples are collected at 4 sites in a cross-section on a quarterly basis.

6.2.4 Proposed Monitoring of Fluvial Sediment and Associated Chemical Constituents in the Mississippi River Basin

The USGS is currently proposing the establishment of a long-term suspended-sediment and solid-phase chemistry monitoring network in the Mississippi River Basin to generate system-wide sediment and sediment-associated chemical budgets and to determine temporal trends. Suspended sediment management has been identified as a critical issue for the Mississippi River. It has been estimated that Mississippi River suspended sediment fluxes to the Gulf of Mexico have declined by as much as 50% to 70% since the 1800's. Much of this decline has been ascribed to the construction of the Missouri River mainstem dams. The loss of sediment delivery to the Gulf of Mexico is believed to have increased erosion along the Louisiana coast; and exacerbated land loss impacts of storm/tidal surges associated with recent hurricanes due to land subsidence in conjunction with the major loss of coastal wetlands and barrier islands. Louisiana coastal and wetland restoration plans/projects are predicated on the assumption that the Mississippi River can be "mined" for material for that purpose. The growing spatial and temporal extent of the Gulf of Mexico hypoxic zone has been ascribed, at least in

part, to nutrient enrichment from Midwestern agricultural sources. It is estimated that Mississippi River Basin suspended sediments deliver about 85%, 30%, and 50%, respectively, of the annual fluxes of P, N, and organic carbon to the northern Gulf of Mexico. Changing suspended-sediment fluxes would seemingly affect the spatial and/or temporal extent of the hypoxic zone. For these reasons, a USGS Ad Hoc Committee on Sediment Data and Monitoring has recommended the establishment of the long-term suspended-sediment and solid-phase chemistry monitoring network in the Mississippi River Basin.

As part of the proposed monitoring network, six sampling stations in the lower Missouri River basin are proposed: 1) Missouri River at Yankton, SD (06467500); 2) James River at Scotland, SD (06478500); 3) Missouri River at Omaha, NE (06610000); 4) Platte River at Louisville, NE (06805500); 5) Kansas River at DeSoto, KS (06892350); and Missouri River at Hermann, MO (06934500). Water-column samples would be collected using the same techniques for collecting NASQAN samples. It would appear that the proposed monitoring would likely be managed under the NASQAN program.

6.2.5 Other USGS Water Quality Monitoring

Table 10 summarizes water quality monitoring being conducted by the USGS along the lower Missouri River and major tributaries to the Missouri River in addition to the NASQAN, Real-Time, and Sediment monitoring. Most of these other stations are fixed monitoring sites where water quality samples are collected on a monthly to bi-monthly basis. Current sampling methods at these sites typically utilize depth and width integrated techniques. Parameter groups currently monitored at most of the USGS sites include physical, nutrient, inorganic, microbiological, biological, and organic constituents. Sediment is monitored at some of the stations.

6.2.5.1 State Water Quality Agencies

States are mandated under the CWA to monitor and periodically assess water quality conditions of all surface waters within their State. Integrated State water quality reports are to be prepared every 2 years assessing water quality conditions and identifying impaired waters. States regularly use collected water quality data to facilitate development and review of water quality standards, TMDLs, NPDES permits, and nonpoint source management plans. To meet these water quality data needs, extensive water quality monitoring networks have been developed by the States.

6.2.6 South Dakota

The South Dakota Department of Environment and Natural Resources (SDDENR) currently maintains four active ambient water quality monitoring stations on the lower Missouri River and its major tributaries. Table 11 lists the locations, sampling frequency, and parameters measured at the four monitoring stations. The water sample collected from the Missouri River at Gavins Point Dam is taken from the Gavins Point Dam powerplant “raw water supply”. This is the same source water sampled by the Omaha District under the Missouri River mainstem dam release monitoring (see Section 6.1.1.1). The samples collected by the SDDENR at the James, Vermillion, and Big Sioux River stations are collected at a 1-foot depth in the deepest part of the river either by wading (preferred) or from a bridge crossing.

Table 10. Other water quality stations currently monitored by the USGS on the lower Missouri River and the lower reaches of major tributaries to the Missouri River.		
Station Location	**USGS Station Number**	**Period of Record**
Stations in Nebraska:		
Little Nemaha River at Auburn, NE	06811500*	1973 to 2009
Big Nemaha River at Falls City NE	06815000*	1973 to 2009
Stations in Iowa:		
Big Sioux River at Akron, IA	06485500	1960 to 2008**
Little Sioux River at Turin, IA	06607500	1968 to 2009
Boyer River at Logan IA	06609500	1945 to 2009
Nishnabotna River above Hamburg IA	06810000	1945 to 2009
Stations in Missouri:		
Missouri River at St. Joseph, MO (RM448)	06818000	1969 to 2009
Missouri River at Sibley, MO (RM336)	06894100	1971 to 2009
Nodaway River near Graham, MO	06817700	1989 to 2009
Platte River at Sharps Station, MO	06821190	1979 to 2009
Blue River at Kansas City, MO	06893150 06893500 06893578	1981 to 2009
Grand River near Sumner, MO	06902000	1962 to 2009
Chariton River near Prairie Hill, MO	06905500	1962 to 2009
Lamine River near Pilot Grove, MO	06907300	1999 to 2009
Osage River below St. Thomas, MO	06926510	1974 to 2009
Gasconade River above Jerome, MO	06930800	1962 to 2009

* Currently a sediment only station.
** Water quality monitoring at the station appears to have be discontinued in 2008.

Table 11. Water quality stations currently monitored by the South Dakota Department of Environment and Natural Resources (SDDENR) along the lower Missouri River and the lower reaches of tributaries to the Missouri River.			
Station Location	**SDDENR Station No.**	**Sampling Frequency**	**Measured Parameters***
Missouri River at Gavins Point Dam	WQM 74	Quarterly	Analysis Group 2
James River near Yankton, SD	WQM 8	Monthly	Analysis Group 2
Vermillion River near Vermillion, SD	WQM 5	Monthly	Analysis Group 2
Big Sioux River near Richland, SD	WQM 32	Monthly	Analysis Group 3

* Analysis Group 2 = Water Temperature, Dissolved Oxygen, Conductivity, pH, Alkalinity, Hardness, Dissolved Solids, Suspended Solids, Total Phosphorus, Dissolved Phosphorus, Ammonia, Nitrate-Nitrite, TKN, *E. coli*, Fecal Coliform, Total Calcium, Total Magnesium, and Total Sodium.

Analysis Group 3 = Analysis Group 2 less Total Calcium, Total Magnesium, and Total Sodium.

6.2.7 Nebraska

As previously discussed (Section 6.1.1.2), the State of Nebraska (NDEQ) has cooperated with the Omaha District since 2003 to monitor ambient water quality conditions along the lower Missouri River. Monitoring site locations and parameter coverage were largely identified by the NDEQ to meet their water quality reporting requirements pursuant to the Federal CWA. Fixed-station monitoring has occurred at seven sites on the Missouri River: Gavins Point Dam tailwaters (RM811); near Maskell, NE (RM774); near Ponca, NE (RM753); at Decatur, NE (RM691); at Omaha, NE (RM619); at Nebraska City, NE (RM563); and at Rulo, NE (RM498). Water quality monitoring consists of year-round collection of monthly near-surface grab samples (i.e., non-isokinetic samples). The grab samples are collected in the river thalweg or from the riverbank in an area of fast current. The collected grab samples are analyzed for numerous parameters, including: physical, nutrient, inorganic, organic, and biological constituents. Field measurements taken at the time of sample collection included temperature, pH, dissolved oxygen, conductivity, ORP, and turbidity.

The NDEQ regularly monitors water quality conditions on the lower reaches of several major tributaries to the Missouri River as part of Nebraska's ambient water quality monitoring network. The primary objective of NDEQ's ambient monitoring network is to provide long term information on the status and trends of water quality in rivers and streams within Nebraska. Secondary objectives include adding to the water quality data base for beneficial use assessments, developing the Section 303d list of impaired waters, TMDLs, surface water quality standards needs, NPDES permitting, and maintain a monitoring presence in all areas of the State. Table 12 lists the monitoring station locations, sampling frequency, and measured parameters for water quality monitoring conducted on Missouri River tributaries as part of the State's ambient water quality monitoring network.

Table 12. Water quality stations, sampling frequency, and parameters currently monitored by the Nebraska Department of Environmental Quality (NDEQ) on the lower reaches of tributaries to the Missouri River.

Station Location	NDEQ Station No.	Sampling Frequency	Measured Parameters*
Papillion Creek at Fort Crook, NE	SMT1PAPIO165	Monthly	F, L1, L2, L3
Platte River at Louisville, NE	SLP1PLATT150	Monthly	F, L1, L2, L3
Weeping Water Creek at Union, NE	SNE1WPNGW135	Monthly	F, L1, L2, L3
Little Nemaha River at Talmage, NE	SNE3LNEMA215	Monthly	F, L1, L2, L3
Big Nemaha River at Preston, NE	SNE2BIGNEM40	Monthly	F, L1, L2, L3

* F= Field measurements: Water Temperature, Dissolved Oxygen, pH, Conductivity, and Turbidity.
L1 = *E. coli* and Immuno-Assay analysis of Atrazine, Acetochlor, and Metolachlor.
L2 = Ammonia, Chloride, Nitrate-Nitrite, TKN, Total Phosphorous, and Total Suspended Solids.
L3 = Dissolved Metals (Calcium, Magnesium, Sodium, Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Silver, and Zinc) and Total Metals (Mercury and Selenium).

6.2.8 Iowa

The Iowa Department of Natural Resources (IDNR) currently does not have any ambient water quality monitoring stations located on the lower Missouri River. The IDNR does regularly monitor water quality conditions on the lower reaches of several major tributaries to the Missouri River as part of Iowa's ambient interior stream monitoring network. The objective of the interior stream monitoring network is to describe and measure water quality geographically throughout all of Iowa and identify possible differences among watersheds and ecoregions. This includes documenting total loading of nutrients and synthetic organic compounds from Iowa to the Mississippi and the Missouri River systems. Table 13 lists station locations, sampling frequency, and measured parameters for water quality monitoring conducted by IDNR on the lower portions of major tributaries to the Missouri River. The sampling methodology for the Iowa interior stream monitoring network is a near-surface grab sample collected in the thalweg of the stream.

Table 13. Water quality stations, sampling frequency, and parameters currently monitored by the Iowa Department of Natural Resources (IDNR) along the lower reaches of tributaries to the Missouri River.

Station Location	USGS Gage	STORET ID	Sampling Frequency	Measured Parameters*
Floyd River near Sioux City, IA	06600500	10750001	Monthly	CP, Herbicides
			Spring and Fall	Priority Pollutants
Monona-Harrison Ditch near Turin, IA	06602400	10670001	Monthly	CP, Herbicides
			Spring and Fall	Priority Pollutants
Little Sioux River near Smithland, IA	06606600	10970001	Monthly	CP, Herbicides
			Spring and Fall	Priority Pollutants
Soldier River near Pisgah, IA	06608500	10430002	Monthly	CP, Herbicides
			Spring and Fall	Priority Pollutants
Boyer River near Logan, IA	06609500	10430001	Monthly	CP, Herbicides
			Spring and Fall	Priority Pollutants

* CP = Temperature, Dissolved Oxygen, pH, Specific Conductance, Ammonia, Nitrate-Nitrite, TKN, CBOD, TSS, Turbidity, Orthophosphate, Total Phosphate, Hardness, TDS, Silica, Fecal Coliform, Chlorophyll, Enterococci, and *E. coli*.

6.2.9 Kansas

The Kansas Department of Health and Environment (KDHE) currently does not have any ambient chemical water quality monitoring stations located on the lower Missouri River. Ambient chemical water quality monitoring stations are located on the lower reaches of the Kansas River at Kansas City and DeSoto, KS. These stations are sampled bi-monthly. A near-surface grab sample is collected on the down-side of a bridge in the apparent thalweg of the river. Parameters measured include: alkalinity, ammonia, chloride, dissolved oxygen, *E. coli,* hardness, metals, TKN, nitrate-nitrite, pesticides, pH, orthophosphate, total phosphorus, specific conductance, sulfate, temperature, TDS, TOC, TSS, and turbidity.

6.2.10 Missouri

The Missouri Department of Natural Resources (MDNR) is cooperating with the USGS to monitor water quality conditions (i.e., water chemistry) on large and medium rivers in the State of Missouri. The monitoring is conducted through a fixed station network that includes sites on the lower Missouri River and its tributaries. Water quality samples are collected on a monthly to bi-monthly basis. Sample collection methods utilize depth and width integrated sampling techniques. Parameter groups currently monitored at most of the USGS sites include physical, nutrient, inorganic, microbiological, biological, and organic constituents. The location of the USGS/MDNR fixed station sites along the lower Missouri River and the lower reaches of major tributaries to the Missouri River are listed in Table 10. These are in addition to the Missouri River USGS NASQAN site at Hermann, MO (06934500), USGS/USACE sediment monitoring site at Kansas City, MO (06893000), and USGS real-time monitoring sites at Waverly, MO (06895500) and Boonville, MO (06909000).

6.3 COMPILATION OF WATER QUALITY MONITORING SITES ALONG THE LOWER MISSOURI RIVER

Attachment 3 provides a diagram of fixed locations where ambient water quality is monitored, on a regular basis, along the lower Missouri River by State water quality agencies, the USGS, and USACE.

7 HISTORIC FLOW CONDITIONS RECORDED ON THE LOWER MISSOURI RIVER AND THE LOWER REACHES OF TRIBUTARIES TO THE RIVER

A summary of historic flows recorded at USGS gaging stations on the lower Missouri River and the lower reaches of tributaries to the river during the 39-year period 1970 through 2008 is given in Table 14. Attachment 4 provides a location diagram of tributaries and USGS flow gaging sites along the lower Missouri River.

Table 14. Summary of historic flows recorded at USGS gaging stations on the lower Missouri River and the lower reaches of its tributaries during the 39-year period 1970 through 2008.

Site*	USGS Gage No.	Period of Record	Mean Daily Flow Statistics (cfs) Min	10th Percentile	25th Percentile	Median	75th Percentile	90th Percentile	Maximum	Mean
Gavins Point Dam (RM811)	USACE	1970-2008	6,000	13,000	18,000	26,000	33,500	42,000	70,100	26,973
Yankton, SD (RM806)	06467500	1970-1995	5,070	14,700	18,500	28,900	35,000	43,900	63,400	28,282
James River (RM800)	06478500	1970-2008	0	18	61	213	806	2,220	27,800	878
Vermillion River (RM772)	06479010	1984-2008	4	17	45	100	284	836	20,200	367
Big Sioux River (RM734)	06485500	1970-2008	4	132	286	748	1,900	4,020	50,600	1,736
Sioux City, IA (RM732)	06486000	1970-2008	5,060	14,900	21,400	30,500	36,900	48,100	103,000	30,746
Floyd River (RM731)	06600500	1970-2008	1	35	74	166	361	719	12,300	329
Decatur, NE (RM691)	06601200	1988-2008	7,130	14,000	18,700	27,700	33,100	47,400	99,900	29,103
Little Sioux River (RM669)	06607500	1970-2008	17	209	389	971	2,040	4,060	28,700	1,708
Soldier River (RM664)	06608500	1970-2008	5	29	52	104	180	317	20,700	174
Boyer River (RM635)	06609500	1970-2008	3	51	114	233	462	898	25,300	431
Omaha, NE (RM616)	06610000	1970-2008	5,460	16,900	25,500	33,900	42,000	54,300	116,000	35,077
Platte River – NE (RM595)	06805500	1970-2008	131	2,210	3,700	6,050	9,080	14,000	138,000	7,671
Weeping Water Ck (RM569)	06806500	1970-2008	1	12	22	44	87	190	34,000	113
Nebraska City, NE (RM562)	06807000	1970-2008	5,200	21,300	30,600	38,800	49,900	63,600	188,000	41,448
Nishnabotna River (RM542)	06810000	1970-2008	32	240	416	900	1,890	3,580	53,700	1,653
Tarkio River (RM508)	06813000	1970-2008	0	18	40	111	284	555	11,100	288
Rulo, NE (RM498)	06813500	1970-2008	7,450	22,700	32,300	41,000	53,600	68,900	289,000	44,787
Big Nemaha River (RM495)	06815000	1970-2008	3	46	78	163	394	1,000	57,600	615
Nodaway River (RM463)	06817700	1982-2008	22	62	115	332	874	2,100	52,000	929
St. Joseph, MO (RM448)	06818000	1970-2008	4,600	23,800	33,700	43,400	57,500	74,600	328,000	48,112
Platte River – MO (RM391)	06821190	1979-2008	12	70	181	575	1,660	4,180	41,200	1,711
Kansas River – KS (RM367)	06892350	1970-2008	323	1,200	1,950	3,880	9,410	21,000	167,000	8,220
Kansas City, MO (RM366)	06893000	1970-2008	6,690	26,400	37,1010	49,900	69,500	95,800	529,000	57,597
Blue River (RM358)	06893500	1970-2008	6	21	31	64	141	328	18,700	198
Waverly, MO (RM293)	06895500	1970-2008	9,000	27,400	38,200	51,000	71,225	100,000	611,000	59,588
Grand River (RM250)	06902000	1970-2008	29	176	391	1,160	3,530	11,500	159,000	4,731
Chariton River (RM239)	06905500	1970-2008	19	61	137	671	1,560	3,200	37,700	1,504
Glasgow, MO (RM226)	06906500	2000-2008	18,400	24,900	32,500	41,700	57,775	93,200	317,000	52,787
Lamine River (RM202)	06906800	1987-2008	0	8	18	64	232	700	47,000	500
Boonville, MO (RM197)	06909000	1970-2008	11,000	30,800	41,300	56,700	82,800	127,000	721,000	70,455
Moreau River (RM139)	06910750	1970-2008	0	10	28	96	279	717	29,600	457
Osage River (RM130)	06926510	1996-2008	320	669	1,260	4,690	17,400	34,400	79,600	11,474
Gasconade River (RM104)	06934000	1986-2008	369	591	781	1,525	3,190	6,300	111,000	3,115
Hermann, MO (RM98)	06934500	1970-2008	13,900	39,600	49,000	71,600	111,000	170,000	739,000	90,874
Mississippi River at St. Louis, MO	07010000	1970-2008	41,200	87,300	118,000	171,000	270,000	402,000	1,050,000	212,886

* For tributaries, RM represents RM on the Missouri River where the confluence of the tributary is located.

8 APPLICATION OF THE CE-QUAL-W2 HYDRODYNAMIC AND WATER QUALITY MODEL TO THE LOWER MISSOURI RIVER

CE-QUAL-W2 is a two-dimensional (longitudinal and vertical) hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients. The model has been applied to rivers, lakes, reservoirs, and estuaries. The following discussion describes model capabilities, limitations, and application for Version 3.6 of the CE-QUAL-W2 model (*taken from "CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.6" Cole and Wells, 2008)*.

8.1 MODEL CAPABILITIES

8.1.1 Hydrodynamic

The model predicts water surface elevations, velocities, and temperatures. Temperature is included in the hydrodynamic calculations because of its effect on water density. The effects of salinity or total dissolved solids/salinity on density and thus hydrodynamics are included only if they are simulated in the water quality module.

8.1.2 Water Quality

Any combination of constituents can be included/excluded from a simulation. The water quality algorithm is modular allowing constituents to be easily added as additional subroutines. The current version (3.6) includes the following water quality state variables in addition to temperature:

1) any number of generic constituents defined by a 0 and/or 1st order decay rate and/or settling velocity and/or Arrhenius temperature rate multiplier that can be used to define any number of the following:
   a) conservative tracer(s)
   b) water age or hydraulic residence time
   c) coliform bacteria(s)
   d) contaminants
2) any number of inorganic suspended solids groups
3) any number of phytoplankton groups
4) any number epiphyton groups
5) any number of CBOD groups
6) ammonium
7) nitrate+nitrite
8) Bioavailable phosphorus (commonly represented by orthophosphate or soluble reactive phosphorus)
9) labile dissolved organic matter
10) refractory dissolved organic matter
11) labile particulate organic matter
12) refractory particulate organic matter
13) total inorganic carbon
14) alkalinity
15) total iron
16) dissolved oxygen
17) organic sediments
18) gas entrainment

19) any number of macrophyte groups
20) any number of zooplankton groups
21) labile dissolved organic matter-P
22) refractory dissolved organic matter-P
23) labile particulate organic matter-P
24) refractory particulate organic matter-P
25) labile dissolved organic matter-N
26) refractory dissolved organic matter-N
27) labile particulate organic matter-N
28) refractory particulate organic matter-N

Additionally, over 60 derived variables including pH, TOC, DOC, TON, TOP, DOP, etc. can be computed internally from the state variables and output for comparison to measured data.

8.1.3 Long Term Simulations

The water surface elevation is solved implicitly, which eliminates the surface gravity wave restriction on the timestep. This permits larger timesteps during a simulation resulting in decreased computational time. As a result, the model can easily simulate long-term water quality responses.

8.1.4 Head Boundary Conditions

The model can be applied to estuaries, rivers, or portions of a waterbody by specifying upstream or downstream head boundary conditions.

8.1.5 Variable Grid Spacing

Variable segment lengths and layer thicknesses can be used allowing for specification of higher resolution where needed. Vertical grid spacing can vary in thickness between waterbodies. The model will adjust surface layer and upstream segment locations for a rising or falling water surface during a simulation.

8.1.6 Water Quality Independent of Hydrodynamics

Water quality can be updated less frequently than hydrodynamics thus reducing computational requirements. However, water quality is ***not*** decoupled from the hydrodynamics (i.e., separate, stand-alone code for hydrodynamics and water quality where output from the hydrodynamic model is stored on disk and then used to specify advective fluxes for the water quality computations). Storage requirements for long-term hydrodynamic output to drive the water quality model are prohibitive for anything except very small grids. Additionally, reduction in computer time is minimal when hydrodynamic data used to drive water quality are input every timestep.

8.1.7 Multiple Inflows and Outflows

Provisions are made for inflows and inflow loadings from point and nonpoint sources, branches, and precipitation. Outflows are specified either as releases at a branch's downstream segment or as lateral withdrawals. Although evaporation is not considered an outflow in the strictest sense, it can be included in the water budget.

8.2 MODEL LIMITATIONS

8.2.1 Hydrodynamics and Transport

The governing equations are laterally and layer averaged. Lateral averaging assumes lateral variations in velocities, temperatures, and constituents are negligible. This assumption may be inappropriate for large waterbodies exhibiting significant lateral variations in water quality. Whether this assumption is met is often a judgment call on the user and depends in large part on the questions being addressed. Eddy coefficients are used to model turbulence. Currently, the user must decide among several vertical turbulence schemes the one that is most appropriate for the type of waterbody being simulated. They are written in the conservative form using the Boussinesq and hydrostatic approximations. Since vertical momentum is not included, the model may give inaccurate results where there is significant vertical acceleration.

8.2.2 Water Quality

Water quality interactions are, by necessity, simplified descriptions of an aquatic ecosystem that is extremely complex. The model is currently limited in its simulation of sediment oxygen demand (SOD). The model includes a user-specified SOD that is not coupled to the water column. SOD only varies according to temperature. The first order model is tied to the water column settling of organic matter. But this models only labile, oxic, sediment decay. The model does not have a sediment compartment that models kinetics in the sediment and at the sediment-water interface, i.e., a complete sediment digenesis model. This places a limitation on long-term predictive capabilities of the water quality portion of the model. Improvements will be made in the future as better means of describing SOD in mathematical terms and time for incorporating the changes into the model become available. The following capabilities have been identified for inclusion in future releases: 1) sediment digenesis algorithm that will compute SOD and sediment to water column nutrient fluxes based on organic matter delivery to the sediments, 2) sediment transport including both cohesive and non-cohesive sediments, and 3) toxics.

8.2.3 Computer Limits

The model places computational and storage burdens on a computer when making long-term simulations. Year-long water quality simulations for a single reservoir can take from a few minutes to days for multiple waterbodies in a large river basin. Applications to dynamic river systems can take considerably longer than reservoirs because of much smaller timesteps needed for river numerical stability. Since the model uses dynamic allocation of memory, the memory required for a simulation is determined at run-time. In cases where the user is running on a Windows 32-bit operating system, the virtual memory is limited to 2GB. If additional memory is required, the code will need to be recompiled using a 64-bit operating system and compiler that can address more memory.

8.2.4 Input Data

The availability of input data is not a limitation of the model itself. However, it is often the limiting factor in the application or misapplication of the model. This cannot be stressed enough. The user should always keep in mind the adage “garage in equals garbage out.”

8.3 MODEL APPLICATION

The following data are needed for model application: 1) geometric data, 2) initial conditions, 3) boundary conditions, 4) hydraulic parameters, 5) kinetic parameters, and 6) calibration data.

8.3.1 Geometric Data

Geometric data are needed to define the finite difference representation of the waterbody. Regarding the lower Missouri River, the following data will be used for setting up input geometry for the Missouri River: 1) channel geometry will be obtained from previous HEC-RAS modeling of the lower Missouri River, and 2) stage-discharge rating curves developed for USGS and USACE gaging stations on the Missouri River. HEC-RAS (Hydrologic Engineering Center-River Analysis System) is a one-dimensional hydraulic flow model that incorporates cross-section river geometry, hydraulic flow characteristics, and flow resistance factors to create a numerical representation of river flow. Common model outputs in a steady-state solution include flow depth, width, water stage, and a one-dimensional average velocity in the channel. The model will also determine off-channel velocities for flood situations, and can vary width, depth, and velocity with time for an unsteady-state solution. Average flow depth and average flow width could be determined from a model solution, as well as the stage-discharge relationship at each cross-section when running multiple different steady-state flow solutions.

8.3.1.1 Computational Grid

The computational grid is the term used for the finite difference representation of the waterbody. Grid geometry is determined by four parameters: 1) longitudinal spacing (segment length), 2) vertical spacing (layer height), 3) average cross-sectional width (cell width), and 4) waterbody slope. The longitudinal and vertical spacing may vary from segment to segment and layer to layer, but should vary gradually from one segment or layer to the next to minimize discretization errors.

A number of factors must be evaluated and weighed against each other when determining longitudinal and vertical spacing. These include:

1) **Areas of strongest gradients.** This factor applies to the metalimnion in freshwater and the pyncocline in saltwater. If the model is not capturing water quality gradients in these regions, then vertical resolution may have to be increased. Similar reasoning applies to areas of longitudinal gradients.

2) **Computational and memory requirements.** The model penalizes the user in two ways when increasing grid resolution. As the number of grid cells goes up, so do computational and memory requirements. In addition, as the dimensions of a grid cell decrease, the timestep must also decrease to maintain numerical stability. As a rule of thumb, it is always desirable to err on the side of greater grid resolution, but at some point the user must give way to the reality of the available computer resources.

3) **Bottom slope.** For reservoirs, the waterbody bottom slope is more accurately modeled as the ratio of cell thickness to cell length approaches the overall bottom slope. For sloping streams/rivers, the ratio is accurately represented by the slope and is typically not of concern.

4) **Results.** Results should not be a function of the computational grid's resolution. Finely discretized grids can be easily coarsened. The coarser grid will have fewer

computational cells and larger average timesteps resulting in decreased runtimes. The computational grid should initially be of high resolution and, if runtimes are excessive, reduced in resolution until the results change substantially. Results should never be a function of the grid resolution.

Applications of the model have used a horizontal grid spacing of 100 to 10,000 meters and a vertical grid spacing of 0.2 to 5 meters. Regardless of the grid spacing used, the user should check to make certain that model predictions are grid independent. This is usually performed by making model simulations with varying grid resolution and using the largest grid that reproduces essentially the same results as those using the smallest grid. Cell widths cannot increase with depth.

8.3.1.2 Bathymetric Data

The next step after determining horizontal and vertical cell dimensions is to determine average cross-sectional widths for each cell. This is an iterative procedure whereby initial bathymetry is input into the model pre-processer and the volume-area-elevation table is then generated by the pre-processor. This table is compared to the “project” table and widths are adjusted to better match the “project” table. For the lower Missouri River, initial cell widths will be derived from past HEC-RAS modeling. Generated surface elevations will be compared to established stage-discharge rating curves at USGS and USACE gaging stations.

The bathymetry input file contains the longitudinal grid spacing, initial water surface elevation, segment orientations, vertical grid spacing, bottom friction, and average cell widths.

8.3.1.3 Branches

CE-QUAL-W2 can simulate a system with any number of waterbodies containing any number of branches. A branch may connect to other branches at its upstream or downstream segment, but a branch may not enter or leave itself. Two branches may not connect at the same segment of another branch.

8.3.2 Initial Conditions

Initial conditions are specified in the control, bathymetry, and vertical and/or longitudinal profile input files. The control file specifies the following initial conditions:

1) **Time** (required). Starting and ending time of the simulation.
2) **Temperature** (required) **and concentrations** (optional). The initial temperature and constituent concentrations. If the grid is not initialized to a single value, then a grid-wide vertical profile can be specified in the vertical profile input file. The option is also available to specify a longitudinally and vertically varying initial value/concentration for temperature and constituents via the longitudinal profile file.
3) **Inflows/outflows** (optional). The number and location of inflows and outflows.
4) **Waterbody type** (required). The waterbody can be specified as either saltwater or freshwater.

8.3.3 Boundary Conditions

The model recognizes the following inflows:

1) **Upstream inflows** (optional). Upstream inflows occur only at a branch's current upstream segment, which may vary during a simulation. The model provides the option to distribute inflows evenly throughout the inflow segment or place inflows according to density. If the upstream inflow is used, then a separate file or inflow, a separate file for temperature, and if constituents are modeled, a separate file containing constituent concentrations for each branch are required.

2) **Tributary inflows** (optional). Tributary inflows or point source loadings may enter any segment of the computational grid. If the current upstream segment number is greater than the segment the tributary enters, then the tributary inflows are added into the current upstream segment to maintain the waterbody water balance. As in upstream inflows, the model provides the option to distribute tributary inflows evenly throughout the inflow segment or place inflows according to their density. An additional option is to place inflows between two specified elevations is also included to better describe point source inflows such as wastewater effluent discharged from a pipe. The number of tributaries and their segment location are specified in the control file. If this option is used, then file requirements for each tributary are the same as for upstream inflows.

3) **Distributed tributary inflows** (optional). Distributed tributary inflows or nonpoint source loadings may be specified for any branch. The flow is distributed throughout the branch weighted by segment surface areas. If this option is used, then file requirements for each distributed tributary are the same as for upstream inflows.

4) **Precipitation** (optional). Precipitation can be specified for each branch and is distributed according to segment surface areas. If this option is used, then file requirements for each branch are the same as for upstream inflows.

5) **Internal inflows** (optional). Flows from gates, pipes, and pumps and over spillways and weirs can be routed internally in the computational grid from one segment to another. This allows application of the model to highly engineered systems.

The model recognizes the following outflows:

1) **Downstream outflows** (optional). Downstream outflows occur only at the downstream segment of a branch. Selective withdrawal where the vertical extent of and flow distribution in the withdrawal zone is calculated by the model is used for all outflows. Additionally, the bottom and top layers below and above which outflow cannot occur can be specified by the user to include the effects of upstream structures that restrict the selective withdrawal zone. Outflow will occur even if the outlet location is above the current water surface layer. When this occurs during a simulation, the outflow comes from the surface layer. This is a necessity when calibrating water surface elevations. A separate file for each branch is required.

2) **Lateral withdrawals** (optional). Lateral withdrawals may be specified for any active cell. The number of withdrawals, their segment location, and their centerline elevation must be specified in the control file. If this option is used, a separate file for each withdrawal is required.

3) **Evaporation** (optional). Evaporation is calculated by the model from air and dew-point temperature and wind speed. If a waterbody loses a significant amount of water from evaporation that is not accounted for in the inflows, then the user should include evaporation. Evaporative heat loss is always included in the heat budget.

4) **Internal outflows** (optional). Flows from gates, pipes, and pumps and over spillways and weirs can be routed internally in the computational grid from one segment to another. This allows application of the model to highly engineered systems.

The model recognizes the following optional head boundary conditions:

1) **External**. The user may specify an external upstream and/or downstream head boundary condition for each branch. This boundary specification is intended primarily for estuarine simulations although it has also been used for river and reservoir applications. If this option is used, a separate file for time-varying elevations, a separate file for vertical temperature profiles, and, if constituents are modeled, a separate file containing vertical profiles for each constituent modeled must be specified for each external head boundary condition.
2) **Internal**. Internal head boundary conditions are specified wherever one branch connects with another branch. The boundary surface elevation, temperatures, and constituent concentrations are calculated internally by the model.

The model requires the following surface boundary conditions:

1) **Surface heat exchange**. Surface heat exchange is calculated by either of two methods using the input variable in the control file. The first method uses equilibrium temperatures and coefficients of surface heat exchange to calculate surface heat exchange. The second method uses a term-by-term accounting for calculating surface heat exchange. For both methods, latitude and longitude are specified in the control file and values for air temperature, dew point temperature, wind speed and direction, and cloud cover must be included in the meteorological file. If available, short wave solar radiation can be input directly into the model.
2) **Solar radiation absorption**. Distribution of solar radiation in the water column is controlled by the fraction of solar radiation absorbed in the surface layer and the attenuation rate due to water, inorganic suspended solids, and organic suspended solids. Values for inorganic and organic suspended solids affect solar radiation only if the constituents are modeled. These values are specified in the control file.
3) **Wind stress**. Wind speed and direction must be supplied in the meteorological file. Wind stress is an extremely important physical process and should be included in all applications. The model allows the user to specify a wind sheltering coefficient which, when multiplied with the wind speed, reduces effects of the wind to take into account differences in terrain from the “met” station and the prototype site. The sheltering coefficient is specified in the wind sheltering file.
4) **Gas exchange**. The wind speed supplied in the meteorological file is also used for computing gas exchange at the water surface if dissolved oxygen and/or total inorganic carbon are simulated. Gas exchange is also affected by the wind sheltering coefficient.

Temperature transport cannot be turned off in the model. Temperature can be treated conservatively by turning off heat exchange computations.

8.3.4 Hydraulic Parameters

The following hydraulic parameters are required by the model:

1) **Dispersion/diffusion coefficients**. The horizontal dispersion coefficients for momentum and temperature/constituents are specified in the control file and are time and space invariant. Sensitivity analyses on numerous applications have shown the model is relatively insensitive to variations in the default values for reservoirs, but can be important in rivers and estuaries. The vertical diffusion coefficients for momentum and

temperature/constituents vary in space and time and are computed by the model. The current model allows for a number of different vertical turbulence algorithms for sloping river sections and estuaries.

2) **Bottom friction**. The current model allows the user the option of specifying longitudinally varying values for the Chezy coefficient or Manning's N for bottom friction. The friction type is specified in the control file. They are used in calculating boundary friction that varies spatially as a function of exposed bottom area and temporally as a function of the flow field. The values are specified in the bathymetry file.

8.3.5 Kinetic Parameters

The use of the kinetic parameters in the model is optional. There are more than 120 coefficients affecting constituent kinetics, although less than 10 are normally adjusted during water quality calibration. The values are specified in the control file. Adjustments to these kinetic coefficients should be considered if simulations include water quality.

8.3.6 Calibration Data

Calibration data are used to provide initial and boundary conditions and assess model performance during calibration. A great deal of thought should go into assessing the amount and type of data necessary to adequately characterize and understand the limnology of a waterbody and to develop the database required to support a water quality modeling effort. Determining the availability of adequate calibration data should be done as early in the study as possible. If the user determines calibration data are inadequate, then immediate steps should be taken to collect sufficient data. Results will be suspect at best and will not withstand scrutiny at worst if the model is applied with insufficient and/or inadequate calibration data. The following discussion provides an overview of data required for the proper application of CE-QUAL-W2:

1) **"In-Pool"**. Proper application of mechanistic water quality models requires at least one set of in-pool observed data. The preferred method is ***at least*** two sets of data encompassing different extremes in prototype (i.e., high and low flow years, warm and cold years, spring phytoplankton bloom and no phytoplankton bloom, etc.). In-pool data is used to set initial conditions and assess the model's ability to reproduce observed conditions. As allowable, all years in which sufficient data are available should be included during model calibration.

2) **Time-Varying Boundary Conditions**. It cannot be overemphasized that data used to drive the model needs to be as accurate as possible. For temperature calibration, this typically means using continuous inflow temperatures or developing regression relationships for inflow temperatures based on flow and air or equilibrium temperature to generate at least daily inflow temperatures. Equilibrium temperature is preferred since it includes more of the mechanisms affecting water temperature.

   For meteorological data, use the most frequent data available. Any time data are averaged (i.e., daily average values), information is lost. For most reservoirs, thermocline depth and shape are a function of two physical mechanisms – wind mixing and convective cooling. Using daily average air temperatures eliminates nighttime convective mixing that can be a very important physical process affecting epilimnetic depths and thermocline shapes for reservoirs. As another example, applying a daily average wind speed and direction can generate an artificial water surface slope that incorrectly drives hydrodynamics. Daily averaging of wind speeds can also result in

much less energy input into the model since the energy input by wind is a function of the wind speed cubed.

For water quality simulations, it is important the user provide accurate initial and time-varying boundary conditions. If nutrient loadings are not adequately characterized, then it will be impossible for the model to accurately reproduce phytoplankton/nutrient/ dissolved oxygen dynamics. It is a waste of time and effort to collect in-pool data in support of water quality modeling when inflow concentrations/loadings have not been adequately characterized since they often drive the system. As in the development of inflow temperatures, regressions relating concentrations/loadings with flow and possibly refined for season should be developed for tributary inflows. Ideally, several storm events should be intensively sampled since this is when loadings are generally the highest to a waterbody. Also point source loadings should be identified and loading estimates obtained. Some estimate of non-point source loadings should also be made. In some cases, meteorological loading estimates should be obtained.

3) **Kinetic Rates**. Because water quality modeling is still very much an art with numerous rate coefficients available for adjusting during calibration, it is highly preferable to obtain actual measurements of these coefficients used in the water quality formulations. If all of the rate coefficients have been determined for a waterbody, then any discrepancies between computed and observed data highlight the model's shortcomings, help to identify the bounds of the model's predictive capabilities, and provide direction for efficient use of resources to provide a better understanding of the system's water quality dynamics.

   Ideally, a model should be used as a starting point for limnological investigations of a waterbody, with the data and formulations continuously refined to reflect the increased understanding of the system and processes gained over time. Unfortunately, this approach is rarely taken in practice due in large part to the expense involved, but also, even more unfortunately, due to inability of aquatic biologists/limnologists and engineers to collaborate.

   Since water quality compartments are coupled, calibration of one compartment may affect other compartments making calibration difficult. *An understanding of the processes modeled as well as knowledge of the system being simulated is an absolute must if the modeling effort is to succeed.* A complete description of kinetic coefficients along with guidelines for appropriate default and a range of literature values is given in the model user manual.

4) **General Guidelines for Water Quality Monitoring to Support Model Application.** Table 15 provides the general guidelines for water quality monitoring, as identified in the model user manual, to support application of the CE-QUAL-W2 model. In regards to monitoring on the lower Missouri River, boundary conditions express the monitoring needs on tributary inflows (including point sources) and in-pool conditions express the monitoring needs on the Missouri River. In-pool parameters specifically applicable to reservoirs may not be needed for Missouri River monitoring.

   Constituents are grouped into four levels (Table 16). Level I include constituents that have no interaction with phytoplankton/nutrient/dissolved oxygen dynamics. Level II includes constituents affecting phytoplankton/nutrient/dissolved oxygen dynamics. Level III includes constituents that interact with Level II constituents, but are not transported. In level IV, alkalinity and total inorganic carbon are transported by the model and are thus state variables. They are necessary for computing pH and carbonate species.

5) **Data Analysis**. An often overlooked step in model applications is data analysis. Data should be reviewed and assessed for reasonableness and to reveal important information about the prototype (i.e., system to be modeled).

Table 15. General guidelines for water quality monitoring to support application of the CE-QUAL-W2 model.

BOUNDARY CONDITIONS		
Minimum Parameters	**Additional Parameters**	**Frequency**
Inflow/Outflow Temperature	Conductivity Dissolved Oxygen pH Total Dissolved Solids[1]	Daily or Continuous
Total Organic Carbon	Dissolved and Particulate Organic Carbon BOD[2]	Weekly with Storm Sampling
Soluble Reactive Phosphorus Total Phosphorus	Total Dissolved Phosphorus Total Inorganic Phosphorus Dissolved Inorganic Phosphorus	Weekly with Storm Sampling
Nitrate+Nitrite Nitrogen Ammonium Nitrogen	Total Kjeldahl Nitrogen Filtered Total Kjeldahl Nitrogen	Weekly with Storm Sampling
	Total Suspended Solids[3] Inorganic and Volatile Suspended Solids	Weekly with Storm Sampling
	Chlorophyll *a* Dissolved Silica[4] Alkalinity	Weekly with Storm Sampling
IN-POOL CONDITIONS		
Minimum Parameters	**Additional Parameters**	**Frequency**
Temperature[5] Dissolved Oxygen[5] pH[5] Conductivity[5]	Total Dissolved Solids[1]	Monthly[6]
Chlorophyll *a*[7]	Phytoplankton Biomass and Type	Monthly
Total Organic Carbon[7]	Dissolved and Particulate Organic Carbon BOD[2]	Monthly
Soluble Reactive Phosphorus Total Phosphorus	Total Dissolved Phosphorus Total Inorganic Phosphorus Dissolved Inorganic Phosphorus	Monthly
Nitrate+Nitrite Nitrogen Ammonium Nitrogen	Total Kjeldahl Nitrogen Filtered Total Kjeldahl Nitrogen	Monthly
	Secchi Depth/Light Transmission	Monthly
	Total Inorganic Carbon Alkalinity	Monthly
	Total Suspended Solids[3] Inorganic and Volatile Suspended Solids	Monthly
	Dissolved/Total Iron[8] Dissolved/Total Manganese[8] Dissolved/Total Silica[8] Total Dissolved Sulfide[8] Sulfate[8] Iron Sulfide[8]	

1 Enough samples to correlate to conductivity – important for density effects.
2 Used to characterize decay rates or organic matter.
3 Suspended solids affect phosphorus partitioning, light penetration, and density.
4 Can be limiting for diatom growth.
5 Preferably bi-weekly samples should be taken at 1-meter intervals.
6 1-meter intervals.
7 Minimum number of samples includes one each in epilimnion, metalimnion, and hypolimnion – preferred number of samples (depending on depth) would be at 3-meter intervals with more frequent metalimnetic sampling.
8 When concerned about sediment release during anoxic periods.

Level[1]	Constituent
I	Total Dissolved Solids (or Salinity)
I	Generic Constituents
I	Inorganic Suspended Solids
II	Dissolved Inorganic Phosphorus
II	Ammonium
II	Nitrate+Nitrite
II	Dissolved Silica
II	Particulate Biogenic Silica
II	Total Iron
II	Labile DOM
II	Refractory DOM
II	Labile POM
II	Refractory POM
II	CBOD
II	Dissolved Oxygen
II	Zooplankton
II	Phytoplankton
III	Epiphyton
III	Organic Sediments
III	Macrophytes
IV	Total Inorganic Carbon
IV	Alkalinity

Table 16. Levels of constituent grouping based on interactions and transport.

[1] Level I = Constituents have no interaction with phytoplankton/nutrient/dissolved oxygen dynamics.
Level II = Constituents affecting phytoplankton/nutrient/dissolved oxygen dynamics.
Level III = Constituents that interact with Level II constituents, but are not transported.
Level IV = Alkalinity and inorganic carbon are transported (state variables) and necessary for computing pH and carbonate species.

8.3.7 Model Simulations

Once the necessary data have been assembled into proper input format, then simulations can begin. The following describes the recommended steps for obtaining meaningful model results when applying the CE-QUAL-W2 model to rivers.

8.3.7.1 Model Preparation

The model includes a preprocessor program that performs checks of the control file for errors that can be detected by the program. The preprocessor should be run periodically during the calibration phase to ensure that errors have not been introduced into the input files. However, do not assume that all is necessarily well if no warning or errors are reported by the preprocessor program.

Additionally, the user should check preprocessor output against inputs to ensure they are correct. Further evaluation of control file input data must be preformed by the user to ensure data the user thinks has been inputted into the model is what the model is actually receiving. Additionally, all time-varying input data should be plotted and screened for errors.

8.3.7.2 Calibration (General)

The next step is to begin calibration runs. Much of the literature refers to this step as calibration and verification in which model coefficients are adjusted to match an observed data set (calibration) and then the model is run on another “independent” data set without adjusting model coefficients to see if the model reproduces observed data in the prototype (verification in most circles, but variously called confirmation, validation, substantiation, etc. as numerous water quality modelers object to the word verification).

This separation is artificial and wrong. If a model does not reproduce observed data (and, more importantly, trends in data) for the “verification” data, then any good modeler will adjust coefficients, review model assumptions, include new processes, or collect additional data to adequately match both sets of data. Often, application to additional sets of data improves the fit to the first. The artificiality of this concept has led to applications in which modelers have used May, June, and July data for “calibration” and August, September, and October data of the same year for “verification” so they can state the model has been “calibrated/verified.”

Ideally, calibration should involve multiple data sets encompassing as many variations and extremes as possible in the prototype. A model’s ability to reproduce prototype behavior under a variety of conditions gives the modeler more confidence in the model’s ability to accurately simulate the prototype under proposed conditions. To put it very simply, a model is a theory about behavior in the real world. A theory is continuously tested against all observed data, and, if it does not match the data, then the theory should either be modified or a new one developed that more closely agrees with observed data.

Calibration is an iterative process whereby model coefficients are adjusted until an adequate fit of observed versus predicted data is obtained. Unfortunately, there are not hard and fast guidelines for determining when an adequate fit is obtained. The user must continually ask “is the model giving useful results based on model formulations, assumptions and input data?” If it is not, then the user must determine if the inability of the model to produce useful results is due to the use of the model in an inappropriate manner (i.e., hydrostatic approximation is invalid, one phytoplankton group is not sufficient to capture phytoplankton/nutrient/dissolved oxygen interactions, wind speed function for evaporation is inappropriate for the waterbody, etc.), model formulations are insufficient to describe known prototype behavior, or if input data are insufficient to describe the system dynamics.

Another important point to keep in mind during calibration is that a model may give inadequate results for a given spatial and/or temporal scale, but at another scale may reasonably represent the dynamics of the prototype. For example, the model may fail to predict a short-term phytoplankton bloom using monthly inflowing phytoplankton and nutrient concentrations, but may adequately represent phytoplankton production over the summer stratification period. The model may thus be useful in determining a waterbody’s long-term response to nutrient loading reduction but be inadequate in addressing short-term responses to a nutrient reduction strategy. In summary, it is not always necessary for model output to match all of the observed data for the model to provide meaningful results.

The usual sequence for calibration is to first calibrate the water budget (or water surface elevation), then calibrate temperature, and finally water quality. Keep in mind water quality calibration can effect temperature calibration.

8.3.7.3 Calibration (River)

Dynamic river modeling can be a challenging endeavor because: 1) velocities are generally high resulting in a lower timestep for numerical stability, 2) shear and bottom friction effects are significant requiring a considerable calibration effort, 3) channel slopes accelerate the fluid, 4) changes in river bathymetry can dramatically affect the velocity field, and 5) dynamic flow rates at low flows can dry up segments causing the model to stop running. One of the original motivations for development of the capability of modeling sloping rivers was to eliminate vertical accelerations in the fluid since the model does not solve the full vertical momentum equation. Keeping this in mind, the grid slope should be chosen to minimize the vertical fluid acceleration.

8.3.7.3.1 <u>Channel Slope</u>

The channel slope is used to compute the gravity force of the channel. This slope should be the slope of the water surface as that is the slope used to accelerate fluid parcels, or the energy grade line, rather than the bottom slope from segment to segment. Rather than going from segment to segment with varying slopes, a general channel slope is used for a collection of segments with similar slope. As the variability in water slope changes, so does the grid slope. Why does the CE-QUAL-W2 model not use a segment-by-segment slope? Consider the “noise” that can be typical in river the cross-sections. Even though the geometry could be set up with variable channel slope for each segment (in the current model this means creating multiple waterbodies or branches for each slope), setting a general channel grade is often simpler and one still has the noise of the bathymetry represented. Computing the slope from one segment to a deep hole would not be correct since the water is flowing along its energy grade line and not the channel slope. Bottom elevations for many of the channel segments rise or have a negative channel slope following a depression. In using a segment-by-segment slope, these variations become unrealistic when represented using a slope for each segment. Therefore, the proper channel slope should be that of the water surface.

In estuarine flow, one usually uses a channel slope of zero and considers fluid accelerations as a result of water surface elevation changes rather than gravity flow down a slope, at least in the estuary section below the head of tide. This is similar in a reservoir, which may have a sloping channel, but a relatively flat water surface.

In some cases, the average channel slope changes and the user must separate the different sections into separate branches or waterbodies. The model can be set up to have almost continuous changes in channel slope by making branches with two segments and changing the slope where it is required. If the choice is to create separate branches, then the surface layer and grid will be the same for all branches. If the choice is to create separate waterbodies, then each waterbody computes a surface layer independently of the other and there can be different vertical grids between waterbodies. How can this be corrected? One way is to decouple one branch from another by splitting them into waterbodies. By splitting the system into more than one waterbody, water can be maintained at various levels throughout the domain since each waterbody has its own separate surface layer. This is another reason why the model does not use segment-by-segment slopes since the surface layer defines the upper layer for a waterbody and in many cases these need to be broken apart into waterbodies to keep water in all segments. In addition, the translation from one waterbody to another introduces some small error into the solution since concentrations, temperatures, and velocities are interpolated from one 2D grid to another. If the model were run in 1D mode with only one vertical layer, then this problem would not exist.

Modeling of shallow streams with large slopes is difficult and takes patience. The model drying out at intermediate sections is often the cause of problems and can be remedied by breaking the system into smaller pieces or waterbodies and/or by adding additional computational cells below the bottom layer at a given segment. Matching river data is accomplished by adjusting friction factors, refining the geometry, and in some cases refining the “equivalent” channel slope if detail has been sacrificed in setting up the model. The quality of the model geometry is essential for good model-data reproducibility in a river system, especially one that is highly irregular in slope and channel width.

Developing a river model is also difficult at low flows since the model may become either unstable during the initial time steps or become dry in a segment. The reason for this is that, in the beginning, an initial water surface elevation is set and the river is “frozen” at that elevation until the model is started, at which point the water starts moving downstream. If a conservative high water surface elevation is set initially in all segments, a wall of water will be sent downstream. If inflows are so small that at the upstream edge of this wave there is too little water, segments can dry out. The model includes a warning and error file that contains information for debugging a river model problem.

8.3.7.3.2 <u>Hydrodynamics, Temperature, and Water Quality</u>

CE-QUAL-W2 is capable of reproducing a wide range of complex hydrodynamics, temperature, dissolved oxygen, nutrient, and phytoplankton and epiphyton regimes in rivers. If the model is not adequately reproducing prototype behavior, the reason is most likely that the bathymetry or important boundary conditions are not being described with sufficient accuracy.

8.3.7.4 (Summary)

For some applications, no amount of model adjustment for data reconstruction will provide acceptable calibration if data are insufficient to describe the dominant forcing functions in the prototype. For these cases, the model can still be used to provide information about the prototype by pointing out data inadequacies, important mechanisms not included in the model but important in the prototype, or inappropriate assumptions used in the model. In these cases, further fieldwork will be necessary to successfully apply the model.

9 CONSIDERATIONS REGARDING THE DEVELOPMENT OF A MONITORING PLAN TO COLLECT WATER QUALITY INFORMATION TO SUPPORT APPLICATION OF THE CE-QUAL-W2 MODEL TO THE LOWER MISSOURI RIVER

9.1 VARIABILITY OF WATER QUALITY CONSTITUENTS IN THE MISSOURI RIVER AND ITS MAJOR TRIBUTARIES

9.1.1 Temporal Variability

9.1.1.1 Seasonal

Seasonal variability in water quality can be significant along the lower Missouri River. Spring runoff can result in large increases in flows and nonpoint source loadings that can have a significant impact on water quality in the lower Missouri River. Maximum water temperatures occur during the summer and can exceed 30°C. During the winter the upper reaches of the lower Missouri River typically ice over.

9.1.1.2 Diurnal

The most significant diurnal variability in water quality on the lower Missouri River is thought to be associated with biological activities. Photosynthesis during the day and respiration at night can result in significant diurnal dissolved oxygen variation. The uptake of nutrients and release of metabolites can also impact various other constituents on a daily basis (e.g., pH, etc.). Diurnal patterns in the discharge of sewage treatment plants and the release of pollutants can have significant localized effects.

Real-time monitoring conducted by the USGS at monitoring sites along the Missouri River may allow for adequate assessment of diurnal variability. Real-time monitoring of water temperature (8 locations) and dissolved oxygen (4 locations) can provide hourly observations of these parameters (see Table 9).

9.1.2 Spatial Variability

9.1.2.1 Longitudinal Variability

Water quality conditions along the lower Missouri River downstream of Gavins Point Dam “degrade” with the occurrence of point and nonpoint source discharges. Tributary inflows can also contribute significant levels of pollutants along the lower Missouri River.

9.1.2.2 Cross-Sectional Variability

The spatial variability of constituents in the cross-section of the Missouri River is dependent upon a number of factors. If the constituent is in the dissolved phase its distribution in the cross-section depends on how well mixed the river is and where the source of entry to the river of the constituent is located. If the constituent is associated with the particulate phase, then in addition to the factors affecting constituents in the dissolved phase there is also the vertical distribution due to sinking of the particulate matter.

9.1.3 Flow-Induced Variability

Flow can generally impact water quality in the lower Missouri River in two ways: 1) the volume of water in the river can assimilate and provide dilution to poorer quality water that is discharged to the river (i.e., greater flow potentially has a greater assimilative capacity), and 2) tributary inflow of poor quality water (especially during runoff conditions) can degrade water quality conditions in the river.

9.1.3.1 Regulated Flows

Flow regulation can generally be defined by the navigation (April through November) and non-navigation (December through March) season. During the navigation season flows released from Gavins Point Dam generally average 35,000 cfs. During the non-navigation season releases from Gavins Point Dam generally average around 12,000 cfs.

9.1.3.2 Runoff Flows

Significant flow can enter the lower Missouri River from tributaries during runoff conditions. During the 39-year period 1970-2008, the mean and maximum daily discharge from

Gavins Point Dam was respectively 26,970 and 70,100 cfs. During the same period the mean and maximum flow recorded at the Hermann, MO gage (RM98) was 90,874 and 739,000 cfs.

9.2 Limitation of the CE-QUAL-W2 Model

A significant limitation of the CE-QUAL-W2 model is that it is laterally-averaged. Variation laterally across the river channel can not be accounted for in the model; however, vertical variation from the water surface to the river bottom can be accounted for with layering.

9.3 Preliminary Segmentation of Lower Missouri River for CE-QUAL-W2 Modeling

The previous QUAL2E modeling of the lower Missouri River delineated the river into 9 reaches that were subdivided into 162 elements equally spaced 5 miles (8.5km) apart (Tillman, 1992).

9.3.1 Preliminary Computational Grid

A preliminary computational grid was developed to facilitate the identification of data needs for model application and the development of a water quality monitoring plan. The following defines the preliminary computational grid:

1) Longitudinal spacing (segment length): equally-spaced segments of either 5,000 meters (≈ 3.1 miles) or 10,000 meters (≈ 6.2 miles) long. This will result in the delineation of about 260 5,000-meter or 130 10,000-meter segments from Gavins Point Dam to St. Louis, MO.
2) Vertical spacing (layer height): equally-spaced layers ½-meter thick. With the maintenance of a 9-foot navigation channel during navigation flows (i.e., 29,000 to 35,000 cfs) this will result in at least 6 “wet” layers per segment. The number of “wet” layers will increase with higher flows during runoff conditions.
3) Average cross-sectional width (cell width): will be defined on a cell-by-cell or segment-by-segment basis based on past HEC-RAS modeling results of the lower Missouri River.
4) Waterbody slope (channel slope): will be defined as a constant for delineated branches. Channel (i.e., water surface) slope will be determined from stage-discharge ratings at USGS gaging stations, water surface profile surveys conducted by the Omaha and Kansas City Districts, and past HEC-RAS modeling results of the lower Missouri River.

9.3.2 Waterbodies

The decision as to where to initially break waterbodies on the lower Missouri River was based on channelization and stabilization of the Missouri River, the availability of weather stations to define meteorological conditions, and significant changes in average discharge (i.e., major tributary inflows).

9.3.2.1 Channelization and Stabilization

The reach of the lower Missouri River from Gavins Point Dam to near Ponca, NE (RM811 to RM752) has not been channelized by construction of dikes and revetments, and has a meandering channel with many chutes, backwater marshes, sandbars, islands, snags, deep pools, and variable current velocities. Although this portion of the river includes some bank stabilization structures, the river remains fairly wide. The Kensler’s Bend reach of the Missouri River extends from Ponca, NE (RM752) to above Sioux City, IA (RM735). The Missouri River

banks have been stabilized with dikes and revetments through this reach, but it has not been channelized. The reach of the Missouri River from the end of the Kensler's Bend reach (RM 735) to the river mouth near St. Louis, MO has been modified over its entire length by an intricate system of dikes and revetments designed to provide a continuous navigation channel without the use of locks and dams. Based on these characteristics, two separate waterbodies, unchannelized and channelized, are identified for these reaches.

9.3.2.2 Weather Stations

Meteorological conditions are important input parameters to the CE-QUAL-W2 model. Each waterbody can be assigned its own meteorological file in the CE-QUAL-W2 model. To better differentiate and define meteorological conditions downstream of Kensler's Bend, additional waterbody breaks were identified based on the availability of weather station data. The preliminary identification of weather stations and the delineation of river reaches they could represent are provided in Table 17. Each of the delineated reaches associated with a weather station would be included as separate waterbodies for modeling purposes.

Table 17. Weather stations tentatively identified to represent meteorological conditions along the lower Missouri River.

Weather Station Location	Airport Symbol	Description of Missouri River Reach to be Represented by Weather Station	Missouri River Reach Length (Miles)
Sioux City, IA	SUX	Gavins Pt. Dam (RM811) to Little Sioux, IA (RM675)	136
Omaha, NE	OMA	Little Sioux, IA (RM675) to Rulo, NE (RM498)	177
Kansas City, MO	MCI	Rulo, NE (RM498) to Waverly, MO (RM293)	205
Columbia, MO	COU	Waverly, MO (RM293) Hermann, MO (RM98)	195
St. Louis, MO	STL	Hermann, MO (RM98) to St. Louis, MO (RM0)	98

9.3.2.3 Significant Tributary Inflow

Significant increases in average flows along the lower Missouri River were identified by comparing tributary flows to immediate upstream flows in the Missouri River. The average tributary flow was compared to the average flow in the Missouri River determined at the nearest upstream gaging station to the tributary. If the average tributary flow was greater than 10 percent of the average upstream Missouri River flow it was deemed a significant tributary inflow. Significant tributary inflows were used to separate adjacent waterbodies along the lower Missouri River. As seen in Table 12, three tributary inflows (i.e., Platte River, NE; Kansas River, KS; and Osage River MO) meet the criteria for a significant tributary inflow.

9.3.2.4 Waterbody Delineation

The preliminary delineation of the lower Missouri River into nine waterbodies for CE-QUAL-W2 modeling purposes are defined in Table 18.

Table 18. Preliminary delineation of the lower Missouri River into waterbodies for CE-QUAL-W2 modeling purposes.

Waterbody	Waterbody Delineation	Channelization	Weather Station	Waterbody Length (Miles)
1	Gavins Point Dam (RM811) through Kensler's Bend (RM735)	Unchannelized	SUX	76
2	Kensler's Bend (RM735) to Little Sioux, IA (RM675)	Channelized	SUX	60
3	Little Sioux, IA (RM675) to Platte River, NE (RM595)	Channelized	OMA	80
4	Platte River, NE (RM595) to Rulo, NE (RM498)	Channelized	OMA	98
5	Rulo, NE (RM498) to Kansas River, KS (RM367)	Channelized	MCI	131
6	Kansas River, KS (RM367) to Waverly, MO (RM293)	Channelized	MCI	74
7	Waverly, MO (RM293) Osage River, MO (RM130)	Channelized	COU	163
8	Osage River, MO (RM130) to Hermann, MO (RM98)	Channelized	COU	32
9	Hermann, MO (RM98) to St. Louis, MO (RM0)	Channelized	STL	98

9.3.3 Branches

The decision as to where to initially break branches within waterbodies for CE-QUAL-W2 modeling purposes will be based on channel slope changes, outflows, and inflows.

9.3.3.1 Channel (Water Surface) Slope

9.3.3.1.1 Stage-Discharge Ratings

Water surface elevations for the lower Missouri River at a flow of 30,000 cfs were determined from stage-discharge rating tables for established gaging stations along the river. Attachment 5 displays a plot of the 30,000 cfs water surface elevation and the river mile location of the gaging station. The plot also gives the calculated slope of the water surface between the gaging stations. Calculated water surface slopes ranged from -0.8015 ft/mi to -1.1150 ft/mi, and are generally less in the downstream half of the lower Missouri River.

9.3.3.1.2 Omaha District Water Surface Profile Survey

In September 2009, the Omaha District conducted a water surface profile survey that included 86 locations from Gavins Point Dam (RM811) to Rulo, NE (RM498). The discharge from Gavins Point Dam through the survey period "averaged" 31,500 cfs. Attachment 6 displays a plot of surveyed water surface elevations and river mile location, and the water surface slope between adjacent survey locations. Attachment 7 displays best-fit linear water surface slopes for delineated segments as determined by direct observation. Water surface slopes of the delineated segments ranged from -0.7621 ft/mi to -1.2651 ft/mi.

9.3.3.1.3 Kansas City District Water Surface Profile Survey

In August and September 2009, the Kansas City District conducted water surface profile surveys that included 164 locations from Rulo, NE (RM498) to St. Louis, MO (RM0). The discharge from Gavins Point Dam through the survey period “averaged” 28,500 cfs. Attachment 8 displays a plot of surveyed water surface elevations and river mile location, and the water surface slope between adjacent survey locations. Attachment 9 displays best-fit linear water surface slopes for delineated segments as determined by direct observation. Water surface slopes of the delineated segments range from -0.7364 ft/mi to -1.0082 ft/mi.

9.3.3.2 Inflows

Provisions are made in the CE-QUAL-W2 model for inflows and inflow loadings from point/nonpoint sources, branches, and precipitation.

9.3.3.2.1 Tributary Inflows and Point Source Loadings

Tributary inflow will not be “modeled” individually as a separate branch or waterbody. Major tributaries will be treated as point sources and will be characterized by “historic” streamflow gaging and water quality monitoring data. Actual point source discharge will be characterized by permit limits, design flows, facility collected DMR data (i.e., discharge monitoring reports), and compliance monitoring data collected by the States.

9.3.3.2.2 Distributed Tributary Inflows and Nonpoint Source Loadings

Distributed tributary inflows or nonpoint source loadings may be specified for any branch. The flow is distributed throughout the branch weighted by segment surface areas. At this time, the availability of nonpoint source loading information does allow for quantifiable longitudinal differentiation of loadings along the lower Missouri River. If such information becomes available that indicates significant longitudinal variation along the lower Missouri River, consideration will be given to the delineation of branches to account for differing nonpoint source loadings.

9.3.3.3 Outflows

Outflows in the CE-QUAL-W2 model are specified either as releases at a branch’s downstream segment or lateral withdrawals. Major outflows (i.e., > 100 MGD ≈ 155 cfs) from the lower Missouri River are identified in Table 19. No “major” irrigation withdrawals occur along the lower Missouri River. Several municipal water supply and power plant facilities have major withdrawals from the lower Missouri River. However, it is noted that the amount of water power plants withdraw from the river for once through cooling is essentially discharged back to the river, albeit, at a warmer temperature.

9.3.3.4 Preliminary Delineation of Branches

Since major tributaries will be treated as point sources and major outflows will not be handled with branching, the preliminary computational grid of the lower Missouri River will have no lateral branches. Longitudinal branching will be utilized to account for changing channel slopes along the river from Gavins Point Dam to St. Louis, MO. Preliminary delineation of river reaches into branches for CE-QUAL-W2 modeling purposes will be based on association of the reach with a “constant” channel slope. Longitudinal branching will also be used, as necessary, to account for varying nonpoint source loadings.

Table 19. Major outflows (i.e., withdrawals > 100 MGD) from the lower Missouri River.			
Facility Name	**Withdrawal Location**	**Average Daily Water Withdrawn (MGD)**	**Water Use**
Midamerican Energy – Neal North	RM718	720	Cooling Water
Midamerican Energy – Neal South	RM717	480	Cooling Water
OPPD – Fort Calhoun Station	RM646	530	Cooling Water
Omaha MUD Florence Water Plant	RM626	230	Drinking Water
OPPD – North Omaha Station	RM625	490	Cooling Water
Midamerican Energy – Council Bluffs	RM606	560	Cooling Water
OPPD – Nebraska City Station	RM556	530	Cooling Water
NPPD – Cooper Brownville Station	RM532	630	Cooling Water
KCPL (Aquila) – Lake Road Station	RM446	110	Cooling Water
KCPL – Iatan Station	RM411	470	Cooling Water
KBPU – Nearman Creek Station	RM379	210	Cooling Water
KBPU – Quindaro Station	RM373	280	Cooling Water
KCMO Water Services Dept. Plant	RM370	120	Drinking Water
Trigen-K.C. Grand Avenue Station	RM366	150	Cooling Water
KCPL Hawthorne Station	RM358	600	Cooling Water
KCPL – Sibley Station	RM336	460	Cooling Water
Ameren – Labadie Power Plant	RM58	1,490	Cooling Water
St. Louis – Howard Bend Plant	RM37	360	Drinking Water
M-AWC Central Plant #1&2	RM36	310	Drinking Water
M-AWC Central Plant #3	RM36		
M-AWC Central North Plant – West	RM21		
M-AWC Central North Plant – East	RM20		

10 PROPOSED MONITORING PLAN FOR THE LOWER MISSOURI RIVER TO FACILITATE APPLICATION OF THE CE-QUAL-W2 MODEL

To facilitate application of the CE-QUAL-W2 model to the lower Missouri River, water quality monitoring is targeted at two efforts: 1) ambient water quality monitoring, and 2) "slug-flow" monitoring of "representative" and "extreme" conditions.

10.1 AMBIENT WATER QUALITY MONITORING

Historical water quality and flow data collected by the USACE, USGS, and State water quality agencies will be used to characterize spatial (longitudinal and vertical), seasonal, and flow-dependent variability on the Missouri River and its tributaries. The collection of additional ambient water quality data will further this effort, especially regarding vertical water quality variation in the Missouri River. Characterized tributary water quality conditions will be used to define tributary inflow conditions for scenario testing.

10.1.1 Missouri River

10.1.1.1 Location of Monitoring Sites

The following criteria are defined to identify water quality monitoring site locations along the lower Missouri River to support application of the CE-QUAL-W2 model.

1) At least one monitoring site should be located on each of the nine delineated waterbodies (Table 18).
2) Monitoring sites should be located at least every 50 to 100 river miles.
3) Monitoring sites should be located an appropriate distance downstream from major tributaries and point sources to represent completely mixed conditions for dissolved constituents.

Table 20 lists the locations of current water quality monitoring sites along the lower Missouri River regarding the nine delineated waterbodies, river mile location, and the location of major point sources. Omaha and Kansas City District Missouri River ambient water quality monitoring sites that are currently being monitored are located in all nine delineated waterbodies. With the exception of RM226 to RM98 and RM98 to RM0, the current Omaha and Kansas City District water quality monitoring sites are located every 50 to 100 river miles along the lower Missouri River. There are a few major point source discharges within 10 river miles upstream of current Missouri River water quality monitoring sites. The Omaha District has a monitoring site located at RM619 which is approximately 6 miles downstream of the OPPD North Omaha Power Plant discharge. The discharge is mainly cooling water and probably influences ambient water temperatures occurring at the site. Given that monitoring at the site includes monthly grab sampling and not continuous temperature monitoring, the power plant discharge is not believed to have a significant impact on the water quality monitoring at the site. The Omaha Missouri River WWTP discharges approximately 5 miles upstream of the USGS NASQAN monitoring site at RM607. The USGS sampling at this site includes isokinetic, depth-integrated EDI samples that would seemingly give unbiased results for loadings at the site. However, caution should be exercised when using water quality data collected at this site given the typical lag in lotic systems regarding metabolic breakdown of organic matter and dissolved oxygen degradation downstream of sewage treatment plant discharges. The Kansas City District has a monitoring site at RM336 and the KCPL Sibley Power Plant discharge is also located in RM336, however the monitoring site is located upstream of the power plant so the discharge will not have any significant impact on the monitoring results.

Table 20. Location matrix for ambient water quality monitoring sites on the lower Missouri River.

Waterbody	Waterbody Delineation	USACE Monitoring Sites		Other Agency Sites		Location of Major Tributaries	Location of Major Point Sources
		District	Location	Agency	Location		
1	Gavins Point Dam (RM811) to Kensler's Bend (RM735)	Omaha	RM811 RM810 RM774 RM753	SDDENR USGS	RM811 RM753[a]		RM805 (Yankton, SD WWTP) RM772 (Vermillion, SD WWTP)
2	Kensler's Bend (RM735) to Decatur, NE (RM691)	Omaha	RM691	USGS USGS	RM732[b] RM691[a]		RM729 (Sioux City, IA WWTP) RM726 (Tyson Meats) RM723 (Terra Industries) RM718 (Mid-American Power Plant) RM716 (Mid-American Power Plant)
3	Decatur, NE (RM691) to Platte River, NE (RM595)	Omaha	RM691 RM619	USGS USGS USGS	RM691[a] RM616[a] RM607[c]		RM647 (Blair, NE WWTP) RM646 (OPPD Power Plant) RM625 (OPPD Power Plant) RM612 (Omaha, NE Missouri River WWTP) RM606 (Mid-American Power Plant) RM605 (Council Bluffs, IA WWTP) RM601 (Bellevue, NE WWTP) RM596 (Omaha, NE Papillion Creek WWTP/CSO)
4	Platte River, NE (RM595) to Rulo, NE (RM498)	Omaha	RM563 RM498	USGS USGS	RM563[b] RM498[a]	RM595 (Platte River)	RM591 (Glenwood, IA WWTP) RM591 (Plattsmouth, NE WWTP/CSO) RM562 (Nebraska City, NE WWTP) RM556 (OPPD Power Plant) RM532 (NPPD Power Plant)
5	Rulo, NE (RM498) to Kansas River, KS (RM367)	Omaha Kansas City	RM498 RM423	USGS USGS	RM498[a] RM448[d]		RM451 (St. Joseph, MO WWTP) RM446 (KCPL Power Plant) RM421 (Atchison, KS WWTP) RM421 (MGP Ingredients) RM411 (KCPL Power Plant) RM396 (Leavenworth, KS WWTP) RM388 (Lansing, KS WWTP) RM368 (Kansas City, KS WWTP) RM368 (Johnson Co. Nelson Comp. WWTP) RM368 (Johnson Co. Mill Creek Reg. WWTP)

Table 20. (Continued).

Waterbody	Waterbody Delineation	USACE Monitoring Sites		Other Agency Sites		Location of Major Tributaries	Location of Major Point Sources
		District	Location	Agency	Location		
6	Kansas River, KS (RM367) to Waverly, MO (RM293)	Kansas City Kansas City	RM336 RM293	USGS USGS USGS	RM366[e] RM336[f] RM293[a]	RM367 (Kansas River)	RM367 (Kansas City, MO WWTP) RM360 (Trigen-Kansas City Power Plant) RM358 (Johnson Co. Blue River WWTP) RM358 (Johnson Co. Tomahawk CK MSD WWTP) RM358 (Johnson Co. DSMB WWTP) RM358 (Kansas City, MO Blue River WWTP) RM357 (Birmingham, MO WWTP) RM357 (Independence Rock Creek WWTP) RM356 (KCPL Power Plant) RM349 (Independence Electric Power Plant) RM336 (KCPL Power Plant)
7	Waverly, MO (RM293) to Osage River, MO (RM130)	Kansas City	RM293 RM226	USGS USGS	RM293[a] RM197[a]		RM195 (Boonville, MO WWTP) RM175 (Columbia, MO WWTP) RM136 (Jefferson City, MO WWTP)
8	Osage River, MO (RM130) to Hermann, MO (RM98)	Kansas City	RM98	USGS	RM98[g]	RM130 (Osage River)	RM115 (Ameren Callaway Power Plant)
9	Hermann, MO (RM98) to St. Louis, MO (RM0)	Kansas City	RM98	USGS	RM98[g]		RM57 (Ameren Labadie Power Plant) RM44 (DCSD Plant #2 WWTP) RM33 (DCSD Plant #1 WWTP) RM30 (MSD Missouri River WWTP) RM27 (St. Charles, MO Missouri River WWTP)

(a) Real-time data only.
(b) Real-time and sediment data only.
(c) NASQAN, real-time, and sediment data site.
(d) Water quality and sediment data site.
(e) Sediment data only.
(f) Water quality data only.
(g) NASQAN and sediment data site.

10.1.1.2 Field Measurements and Sample Collection

A limitation of the CE-QUAL-W2 model is that it is a laterally-averaged model. Thus, variation laterally across the river channel can not be accounted for and the model assumes lateral homogeneity. As discussed above, Missouri River monitoring sites need to be located a great enough distance downstream from major tributaries and point sources to ensure complete mixing of dissolved constituents has occurred. The model can account for vertical variation from the water surface to river bottom with layering. Considering these limitations and abilities, the following criteria are defined to facilitate the collection of field measurements and water quality samples to support application of the CE-QUAL-W2 model to the lower Missouri River.

1) To represent lateral conditions:
    - Sites should be located a great enough distance downstream from major tributaries and point sources to ensure that dissolved constituents have completely mixed.
    - Field measurements and water samples should be taken in the thalweg of the river.
2) To quantify vertical variation:
    - Appropriate field measurements (i.e., temperature, dissolved oxygen, pH, conductivity, ORP, turbidity, chlorophyll) should be taken as a depth-profile (½-meter increments if possible, otherwise 1-meter increments).
    - Depth-discrete water quality samples should be collected at near-surface, middle, and near-bottom depths.
    - To reduce analytical costs, dissolved constituents should only be analyzed in the near-surface sample; and constituents associated with the particulate phase should be analyzed in the near-surface, mid-depth, and near-bottom samples. However, if depth-profile measurements indicate significant stratification (i.e., significant differences in near-surface and near-bottom temperature, dissolved oxygen, conductivity, pH, or ORP), dissolved constituents should also be analyzed in the mid-depth and near-bottom samples.

10.1.1.3 Parameters to be Measured and Analyzed

Table 21 lists the water quality parameters identified for measurement and analyses to facilitate application of the CE-QUAL-W2 model to the lower Missouri River.

10.1.1.4 Assessment of Cross-Sectional Variability

As discussed, the CE-QUAL-W2 is a laterally-averaged model (assumes lateral homogeneity). To represent "lateral conditions" water quality measurements and sampling will be done in the thalweg of the river. The amount of "spatial bias" associated with thalweg sampling could possibly be estimated by comparing thalweg sampling results to USGS isokinetic, depth-integrated EDI sampling results. The opportunity exists for concurrent thalweg and isokinetic sampling at USGS NASQAN sites. Two NASQAN sites are located on the Missouri River at Omaha, NE (RM607) and Herman, MO (RM98). As discussed earlier, the Omaha NASQAN site is located 5 miles downstream of the Omaha, NE Missouri River Sewage Treatment Plant. The close proximity of the Omaha NASQAN site to the sewage treatment plant discharge does not meet the "thalweg monitoring criteria" of being located a great enough distance downstream from major point sources to ensure that dissolved constituents have completely mixed. The NASQAN site at Herman, MO does not have these concerns and the site is sampled by the Kansas City District. If the USGS NASQAN and Kansas City District water quality sampling at the Herman, MO site could be coordinated, the isokinetic and thalweg sampling results could be compared. Assessment of the sampling techniques would require

Table 21. Ambient water quality parameters identified for measurement and analyses.				
Parameter	**Sampling Method**	**Near Surface**	**Mid Depth**	**Near Bottom**
Field Measurements:				
Water Temperature	HydroLab	Profile*	Profile*	Profile*
Dissolved Oxygen (mg/l)	HydroLab	Profile*	Profile*	Profile*
Dissolved Oxygen (% saturation)	HydroLab	Profile*	Profile*	Profile*
pH	HydroLab	Profile*	Profile*	Profile*
Conductivity	HydroLab	Profile*	Profile*	Profile*
Oxidation-Reduction Potential	HydroLab	Profile*	Profile*	Profile*
Turbidity	HydroLab	Profile*	Profile*	Profile*
Chlorophyll *a*	HydroLab	Profile*	Profile*	Profile*
Secchi Transparency	Pole-mounted Secchi disk	X		
Water Sample Analyses:				
Alkalinity	Churn Bucket	X		
Biochemical Oxygen Demand (5-day)	Churn Bucket	X		
Carbon, Dissolved Organic	Churn Bucket	X		
Carbon, Total Organic	Churn Bucket/Van Dorn	X	X	X
Chlorophyll *a*	Churn Bucket	X		
Nitrogen, Ammonia	Churn Bucket	X		
Nitrogen, Kjeldahl	Churn Bucket/Van Dorn	X	X	X
Nitrogen, Nitrate-Nitrite	Churn Bucket	X		
Phosphorus, Dissolved	Churn Bucket	X		
Phosphorus-Ortho, Dissolved	Churn Bucket	X		
Phosphorus, Total	Churn Bucket/Van Dorn	X	X	X
Phytoplankton, Taxa and Biomass	Churn Bucket	X		
Sediment, Total Suspended	Churn Bucket/Van Dorn	X	X	X
Silica, Dissolved	Churn Bucket	X		
Solids, Total Dissolved	Churn Bucket	X		
Solids, Total Suspended	Churn Bucket/Van Dorn	X	X	X
Sulfate	Churn Bucket	X		
* Profile should be taken in ½-meter depth increments.				

that USGS and Kansas City District sampling at the site be conducted preferably on the same day. Sampling within a few days might be acceptable if climatic, flow and other conditions remain constant over the period.

10.1.2 Major Missouri River Tributaries

Major tributaries to the lower Missouri River were identified based on historic tributary flow as a percentage of the historic upstream Missouri River flow. Table 22 shows historic median and mean tributary flow as a percentage of historic median and mean upstream Missouri River flow. Major tributaries were defined as tributaries contributing more than 0.5 percent of the mean historic upstream Missouri River flow based on USGS gaging records.

Based on this definition the following tributaries are deem major tributaries: James River, SD; Vermillion River, SD; Big Sioux River, IA/SD; Floyd River, IA; Little Sioux River, IA; Soldier River, IA; Boyer River, IA; Platte River, NE; Nishnabotna River, IA; Tarkio River, MO; Big Nemaha River, NE; Nodaway River; Mo. Platte River, MO; Kansas River, KS; Grand River, MO; Chariton River, MO; Lamine River, MO; Moreau River, MO; Osage River, MO; and Gasconade River, MO. At a minimum, water quality data on these major tributaries is needed to calibrate the CE-QUAL-W2 model and to conduct scenario testing. These tributaries will be sampled during "slug-flow" monitoring to facilitate model calibration. Historic water quality data and ongoing ambient water quality monitoring by various agencies may be adequate to define tributary water quality conditions for scenario testing. If these water quality data prove to be inadequate, additional tributary water quality monitoring should be pursued.

Table 22. Identification of major tributaries based on tributary flow as a percentage of upstream Missouri River flow.

Site*	USGS Gage No.	Period of Record	Median	Percent Upstream Missouri River Median Flow	Mean	Percent Upstream Missouri River Mean Flow
Yankton, SD (RM806)	06467500	1970-1995	28,900		28,282	
James River (RM800)	06478500	1970-2008	213	0.007	878	0.031
Vermillion River (RM772)	06479010	1984-2008	100	0.003	367	0.013
Big Sioux River (RM734)	06485500	1970-2008	748	0.026	1,736	0.061
Sioux City, IA (RM732)	06486000	1970-2008	30,500		30,746	
Floyd River (RM731)	06600500	1970-2008	166	0.005	329	0.011
Decatur, NE (RM691)	06601200	1988-2008	27,700		29,103	
Little Sioux River (RM669)	06607500	1970-2008	971	0.035	1,708	0.059
Soldier River (RM664)	06608500	1970-2008	104	0.004	174	0.006
Boyer River (RM635)	06609500	1970-2008	233	0.008	431	0.015
Omaha, NE (RM616)	06610000	1970-2008	33,900		35,077	
Platte River – NE (RM595)	06805500	1970-2008	6,050	0.178	7,671	0.219
Weeping Water Ck (RM569)	06806500	1970-2008	44	0.001	113	0.003
Nebraska City, NE (RM562)	06807000	1970-2008	38,800		41,448	
Nishnabotna River (RM542)	06810000	1970-2008	900	0.023	1,653	0.040
Tarkio River (RM508)	06813000	1979-2008	111	0.003	288	0.007
Rulo, NE (RM498)	06813500	1970-2008	41,000		44,787	
Big Nemaha River (RM495)	06815000	1970-2008	163	0.004	615	0.014
Nodaway River (RM463)	06817700	1982-2008	332	0.008	929	0.021
St. Joseph, MO (RM448)	06818000	1970-2008	43,400		48,112	
Platte River – MO (RM391)	06821190	1979-2008	575	0.013	1,711	0.036
Kansas River – KS (RM367)	06892350	1970-2008	3,880	0.089	8,220	0.171
Kansas City, MO (RM366)	06893000	1970-2008	49,900		57,597	
Blue River (RM358)	06893500	1970-2008	64	0.001	198	0.003
Waverly, MO (RM293)	06895500	1970-2008	51,000		59,588	
Grand River (RM250)	06902000	1970-2008	1,160	0.023	4,731	0.079
Chariton River (RM239)	06905500	1970-2008	671	0.013	1,504	0.025
Glasgow, MO (RM226)	06906500	2000-2008	41,700		52,787	
Lamine River (RM202)	06906800	1987-2008	64	0.002	500	0.009
Boonville, MO (RM197)	06909000	1970-2008	56,700		70,455	
Moreau River (RM139)	06910750	1970-2008	96	0.002	457	0.006
Osage River (RM130)	06926510	1996-2008	4,690	0.083	11,474	0.163
Gasconade River (RM104)	06934000	1986-2008	1,525	0.027	3,115	0.044
Hermann, MO (RM98)	06934500	1970-2008	71,600		90,874	

10.2 Slug-Flow Sampling for CE-QUAL-W2 Model Calibration

Slug-flow sampling will be used to collect water quality data for “calibrating” the CE-QUAL-W2 model to the lower Missouri River. Slug-flow sampling would be targeted over the 3-year period of April 2010 through March 2013. Slug-flow sampling is defined as sampling a “slug” of water, based on time-of-travel, as it moves down the Missouri River from Gavins Point Dam to St. Louis, MO (see Table 1). Based on time-of-travel, water quality samples would be collected at the USACE’s Missouri River ambient stations and two additional sites: RM160 and RM44. Major tributaries along the river will also be sampled based on the slug of water in the Missouri River passing the confluence of the tributaries. The major tributaries will be sampled immediately upstream of their confluence with the Missouri River. Slug-flow sampling of the Missouri River would be for the same parameters identified in Table 21. Slug-flow sampling of the tributaries would be similar to sample collection on the Missouri River except that a composite water sample will be created for analysis. The composite sample will be created by collecting near-surface, mid-depth, and near-bottom samples of equal volumes with a Van Dorn sampler and combining them in a churn-bucket. If possible, field measurements will be taken as a depth profile; otherwise, field measurements will be taken at the surface and from the prepared composite sample. Effluent data will be compiled for major point sources along the lower Missouri River to describe effluent conditions as the slug of water passed the discharge locations.

As resources allow, slug-flow sampling will be targeted to monitor the following conditions over the 3-year period: 1) spring runoff, 2) maximum summer thermal conditions, 3) low flow (i.e., non-navigation releases), and 4) a “representative” non-runoff influenced navigation flow. To monitor these conditions, slug-flow sampling will be targeted for March through October. It is proposed that slug-flow sampling be conducted jointly by the Omaha and Kansas City Districts. The Omaha District could sample the Missouri River and major tributaries from Gavins point Dam to Rulo, NE including the Big Nemaha River. The Kansas City District could sample the Missouri River and major tributaries downstream of Rulo, NE with the exception of the Big Nemaha River. Sample collection would be coordinated such that when the Omaha District completed sampling at Rulo, NE the Kansas City District would initiate sampling to follow the slug of water downstream to St. Louis, MO.

10.3 Sampling and Analysis Plans

Sampling and Analysis Plans (SAPs) will be developed to implement to proposed water quality monitoring of the lower Missouri River. The Omaha and Kansas City District’s will each develop SAPs to implement the appropriate ambient water quality monitoring. A separate SAP will be jointly developed by the two Districts to implement the proposed “slug-flow” water quality monitoring.

11 REFERENCES

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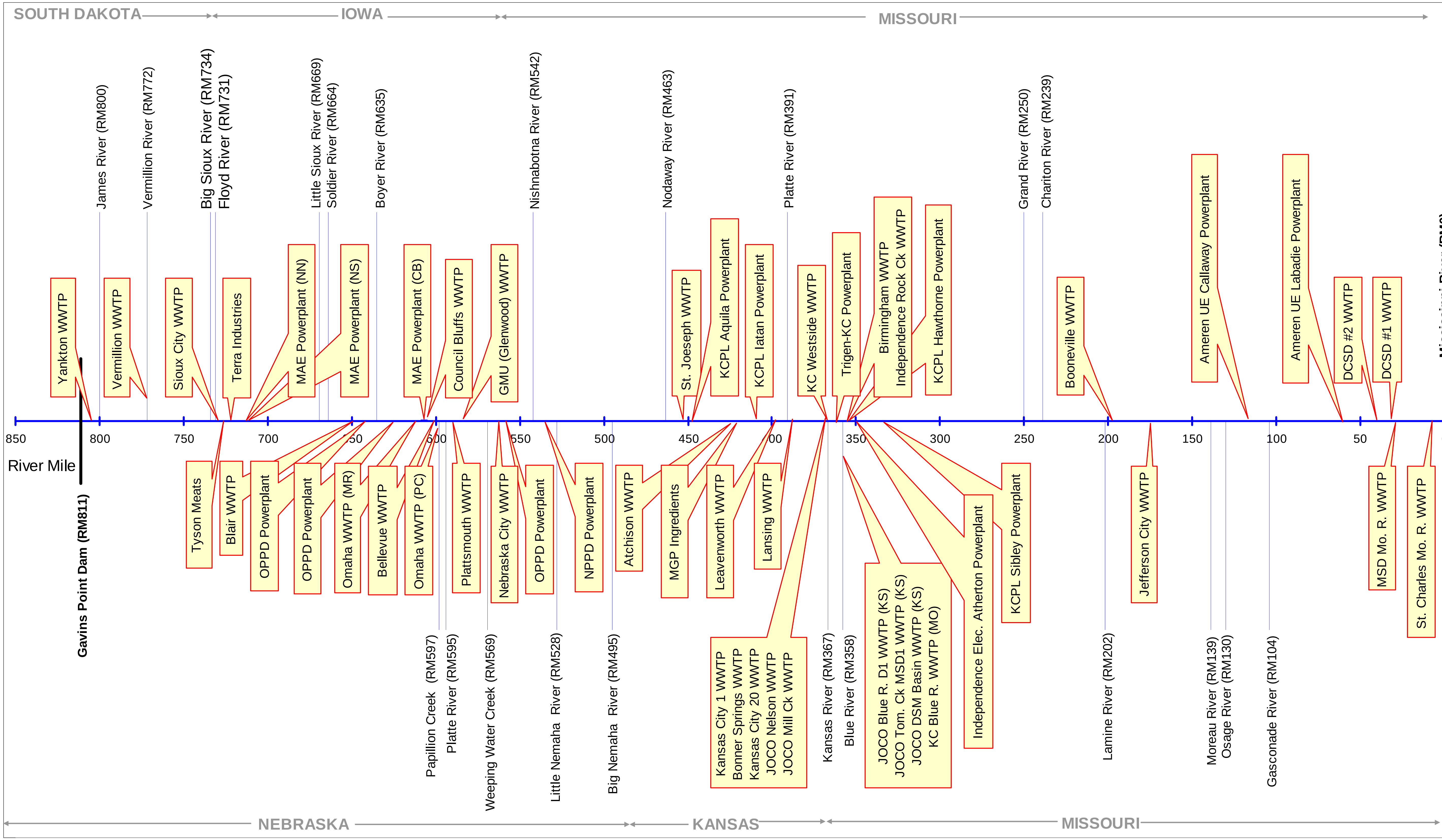
Attachment 1. Diagram of where major point source discharges are located along the lower Missouri River.



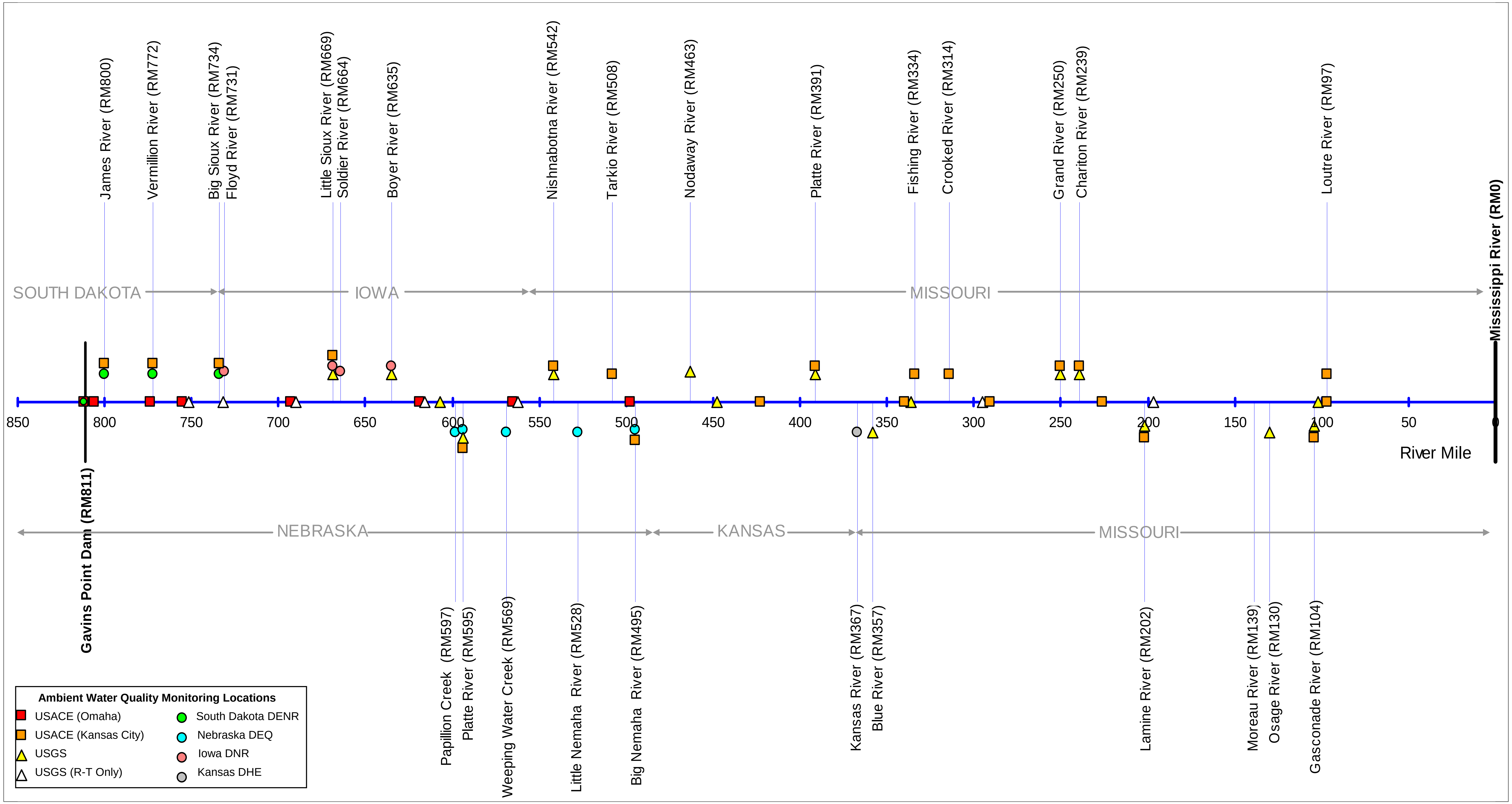
Attachment 2. Constituents measured in USGS's NASQAN program.

USGS Laboratory Schedule/Lab Code	Analyte	Parameter Code
Field parameter	Temperature	00010
Field parameter	Specific conductance	00095
Field parameter	Dissolved oxygen	00300
Field parameter	pH	00400
Field parameter	Alkalinity, filtered, field	39086
998/1201	Calcium	00915
998/1201	Magnesium	00925
998/1201	Sodium	00930
998/1201	Potassium	00935
998/1201	Chloride	00940
998/1201	Sulfate	00945
998/1201	Fluoride	00950
998/1201	Silica	00955
998/1201	Arsenic	01000
998/1201	Boron	01020
998/1201	Iron	01046
998/1201	Strontium	01080
998/1201	Vanadium	01085
998/1201	Lithium	01130
998/1201	Selenium	01145
998/1201	Residue, 180 degrees Celsius (TDS)	70300
997/1010/1069	Nitrogen, ammonia, filtered	00608
997/1010/1069	Nitrogen, nitrite, filtered	00613
997/1010/1069	Nitrogen, ammonia + organic (Kjeldahl), filtered	00623
997/1010/1069	Nitrogen, ammonia + organic (Kjeldahl), unfiltered	00625
997/1010/1069	Nitrogen, nitrite + nitrate, filtered	00631
997/1010/1069	Phosphorus, unfiltered, total as phosphorus	00665
997/1010/1069	Phosphorus, filtered	00666
997/1010/1069	Phosphorus, phosphate, ortho, filtered	00671
997/1010/1069	Carbon, organic, filtered, recoverable (DOC)	00681
997/1010/1069	Carbon, inorganic, sediment, suspended (PIC)	00688
997/1010/1069	Carbon, organic, sediment, suspended, recoverable (POC)	00689
997/1010/1069	Carbon, inorganic + organic, sediment, suspended (PC)	00694
997/1010/1069	Total nitrogen	49570
997/1010/1069	Ultraviolet absorbing organic constituents - 254 nm	50624
997/1010/1069	Ultraviolet absorbing organic constituents - 280nm	61726
LC 8096	Ultraviolet absorbing organic constituents - 412nm	66700
LC 8097	Carbon, inorganic, filtered (DIC)	00691
SusSed	Suspended sediment, percent finer than 62 microns	70331
SusSed	Suspended sediment	80154

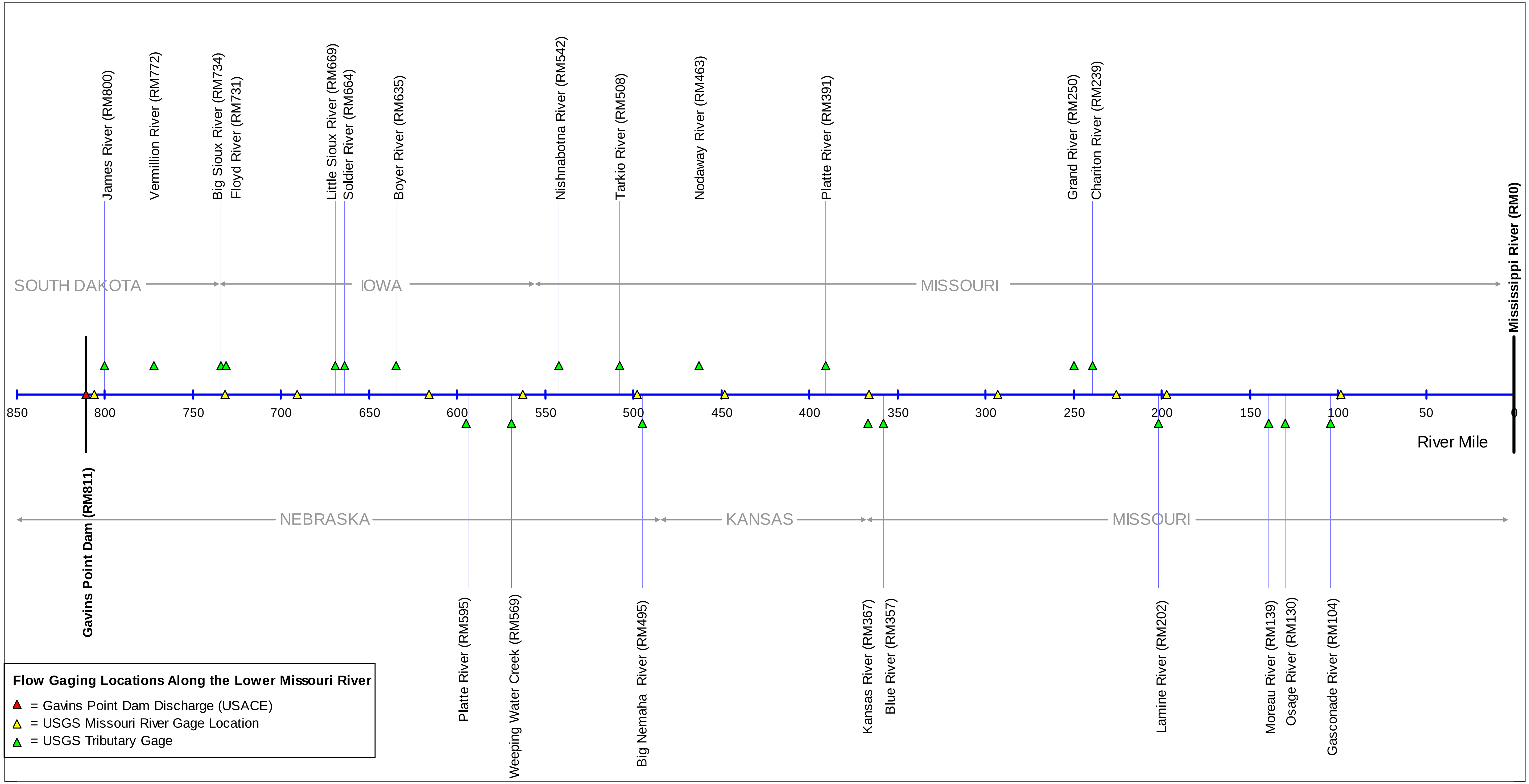
2033	Terbuthylazine	04022
2033	Hexazinone	04025
2033	Simazine	04035
2033	Prometryn	04036
2033	Prometon	04037
2033	2-Chloro-4-isopropylamino-6-amino-s-triazine {CIAT}	04040
2033	Cyanazine	04041
2033	Fonofos	04095
2033	alpha-Endosulfan	34362
2033	Dicrotophos	38454
2033	Dichlorvos	38775
2033	Chlorpyrifos	38933
2033	Dieldrin	39381
2033	Metolachlor	39415
2033	Malathion	39532
2033	Diazinon	39572
2033	Atrazine	39632
2033	Alachlor	46342
2033	Acetochlor	49260
2033	1-Naphthol	49295
2033	Cyfluthrin	61585
2033	Cypermethrin	61586
2033	Endosulfan sulfate	61590
2033	Fenamiphos	61591
2033	Iprodione	61593
2033	Isofenphos	61594
2033	lambda-Cyhalothrin	61595
2033	Metalaxyl	61596
2033	Methidathion	61598
2033	Myclobutanil	61599
2033	Oxyfluorfen	61600
2033	Phosmet	61601
2033	Tefluthrin	61606
2033	Tribufos	61610
2033	2-Chloro-2,6-diethylacetanilide	61618
2033	2-Ethyl-6-methylaniline	61620
2033	3,4-Dichloroaniline	61625
2033	3,5-Dichloroaniline	61627
2033	4-Chloro-2-methylphenol	61633
2033	Azinphos-methyl-oxon	61635
2033	Chlorpyrifos, oxygen analog	61636
2033	Diazinon, oxygen analog	61638
2033	Disulfoton sulfone	61640

2033	Ethion monoxon	61644
2033	Fenamiphos sulfone	61645
2033	Fenamiphos sulfoxide	61646
2033	Malaoxon	61652
2033	Paraoxon-methyl	61664
2033	Phorate oxygen analog	61666
2033	Phosmet oxon	61668
2033	Terbufos oxygen analog sulfone	61674
2033	Fipronil	62166
2033	Fipronil sulfide	62167
2033	Fipronil sulfone	62168
2033	Desulfinylfipronil amide	62169
2033	Desulfinylfipronil	62170
2033	Tebuconazole	62852
2033	cis-Propiconazole	79846
2033	trans-Propiconazole	79847
2033	Ethion	82346
2033	Metribuzin	82630
2033	2,6-Diethylaniline	82660
2033	Trifluralin	82661
2033	Dimethoate	82662
2033	Phorate	82664
2033	Parathion-methyl	82667
2033	EPTC	82668
2033	Tebuthiuron	82670
2033	Molinate	82671
2033	Ethoprophos	82672
2033	Benfluralin	82673
2033	Carbofuran	82674
2033	Terbufos	82675
2033	Propyzamide	82676
2033	Disulfoton	82677
2033	Propanil	82679
2033	Carbaryl	82680
2033	Thiobencarb	82681
2033	Dacthal	82682
2033	Pendimethalin	82683
2033	Propargite	82685
2033	Azinphos-methyl	82686
2033	cis-Permethrin	

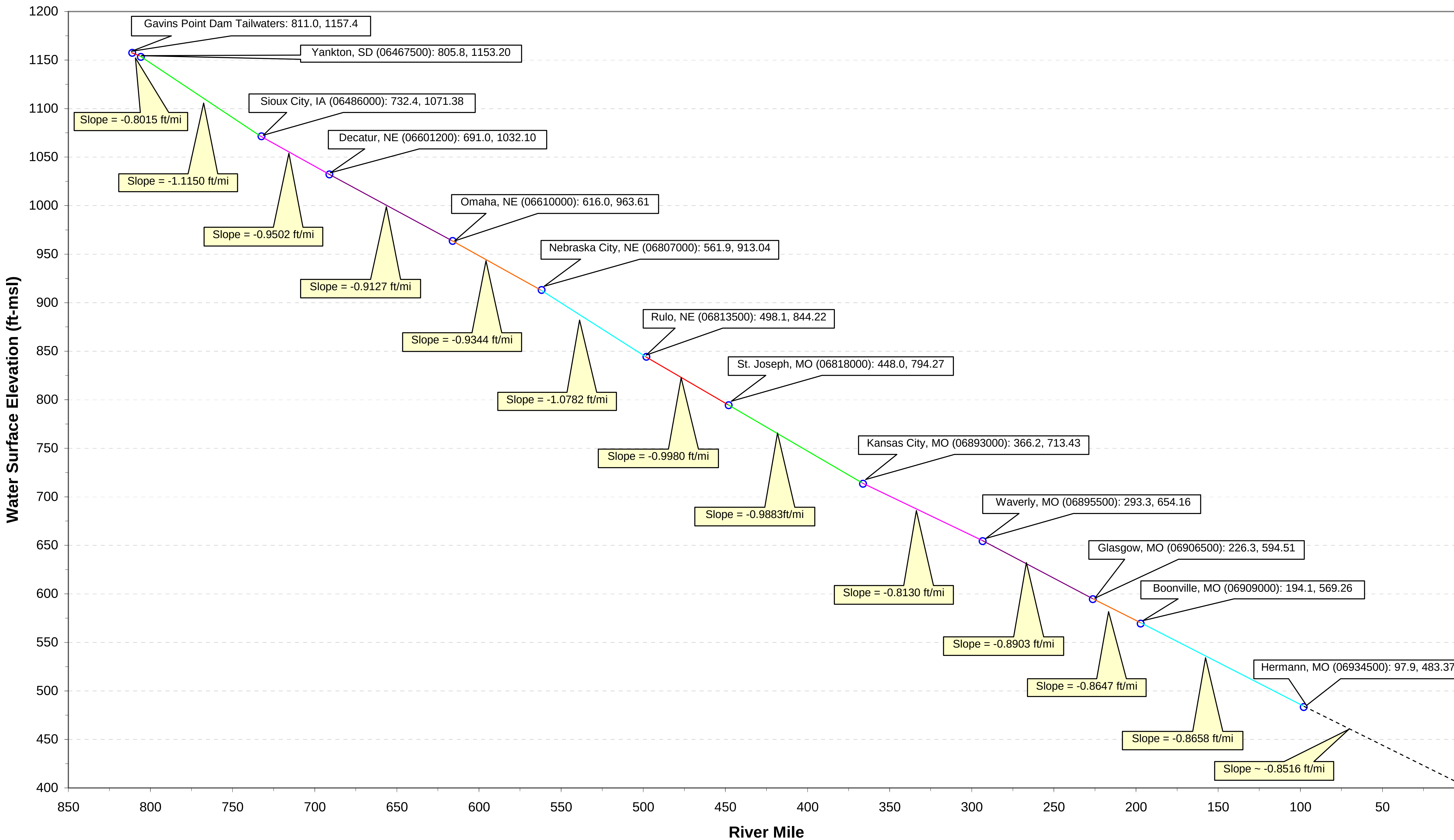
Attachment 3. Diagram of locations where ambient water quality is regularly monitored along the lower Missouri River by the USACE, USGS, and State water quality agencies.



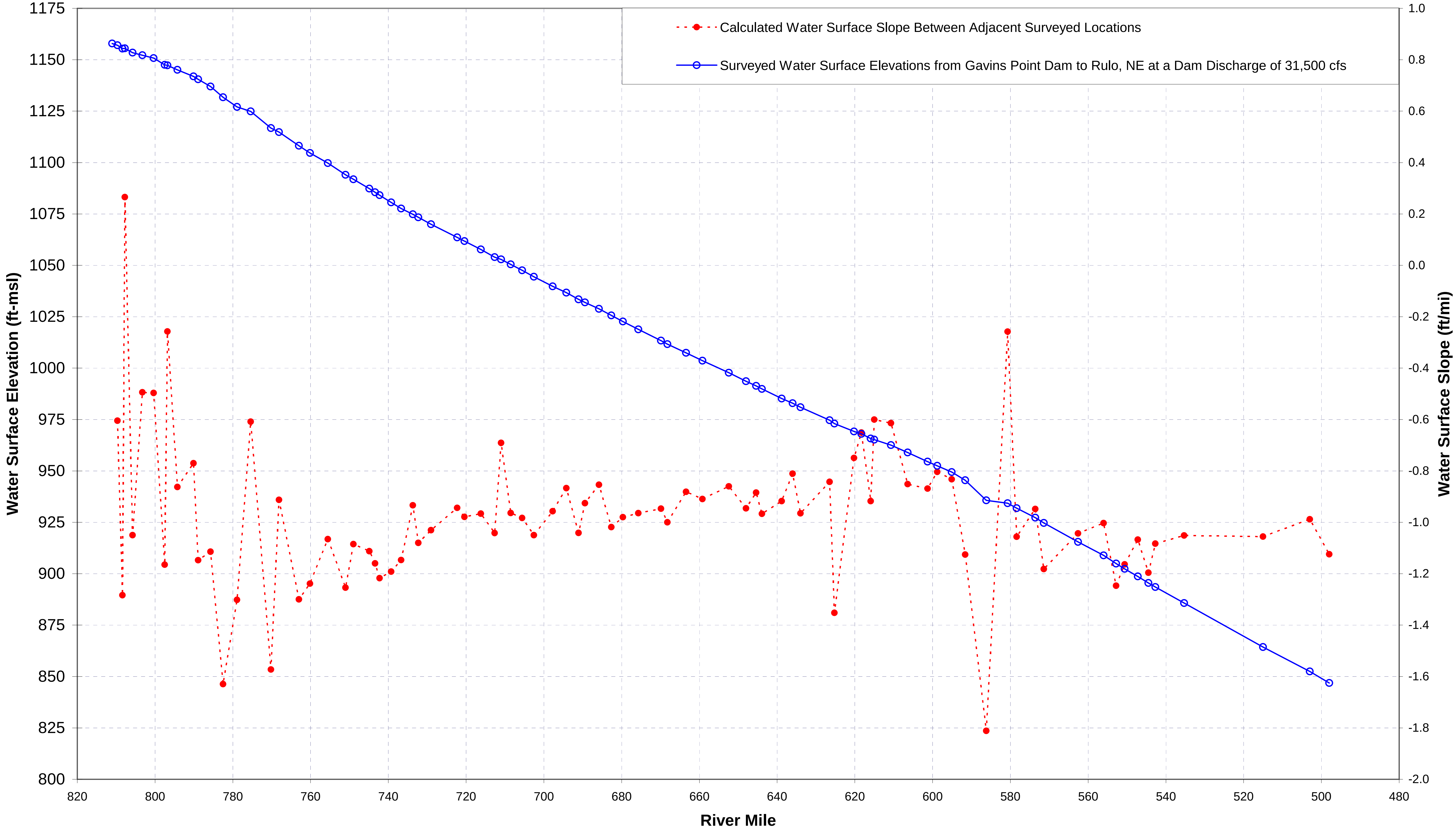
Attachment 4. Diagram of where USGS flow gaging stations are located along the lower Missouri River.



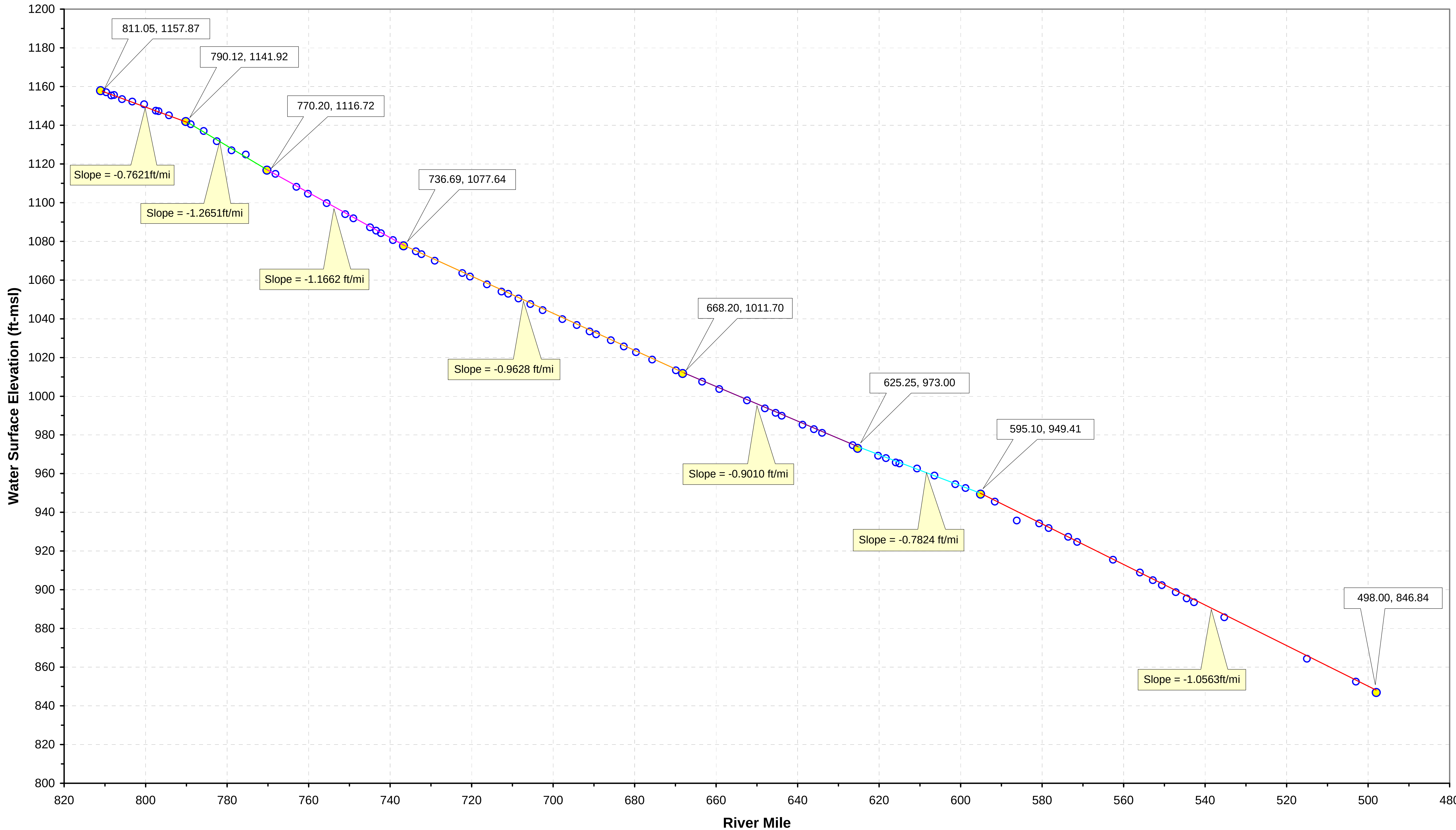
Attachment 5. Estimated water surface elevations of the Missouri River at a river flow of 30,000 cfs. Water surface elevations based on stage-discharge rating tables developed for USGS gaging stations along the Missouri River.



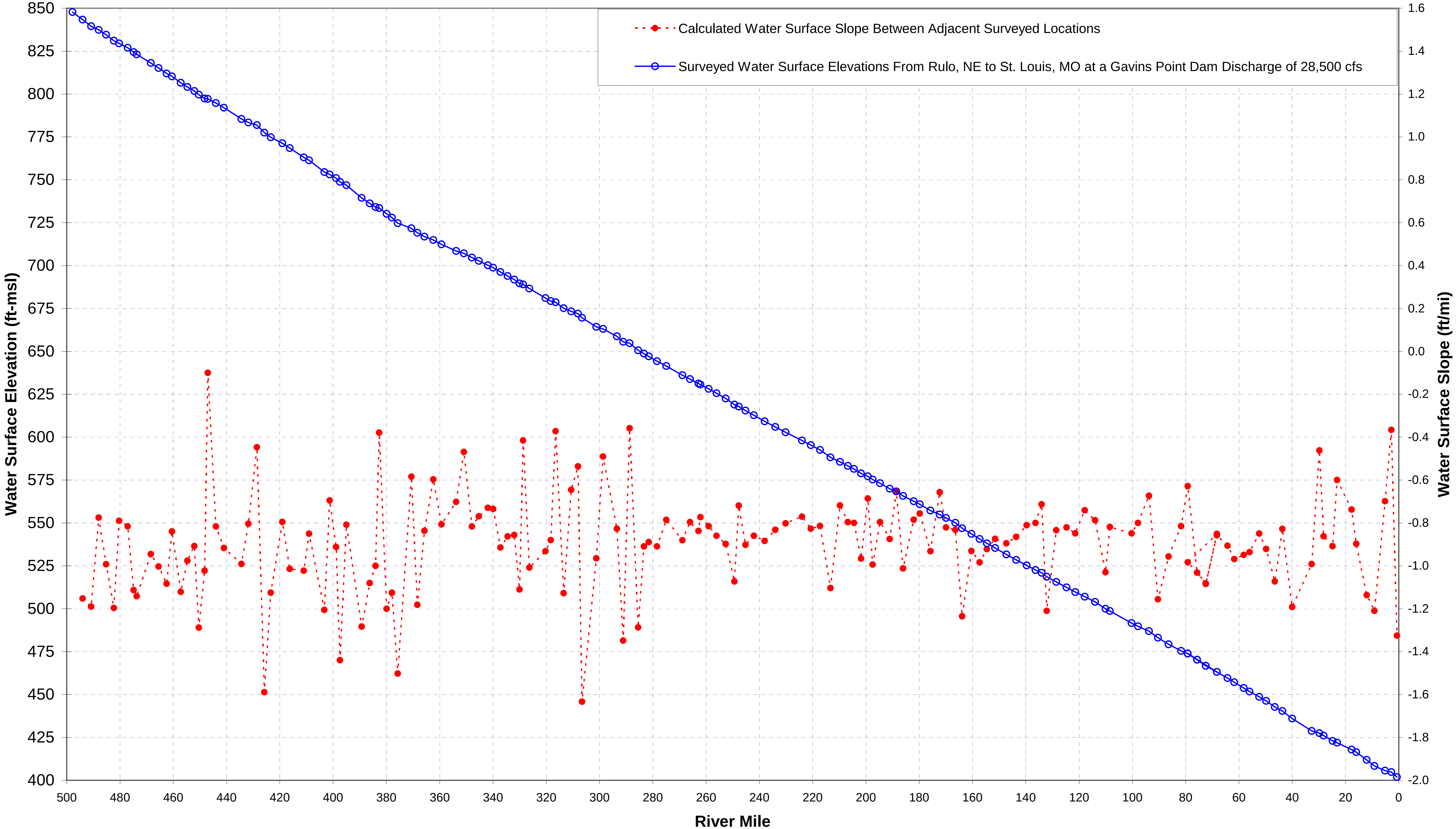
Attachment 6. Water surface profiles of the Missouri River surveyed by the Omaha District at 86 locations from Gavins Point Dam to Rulo, NE in September 2009. Discharge from Gavins Point Dam during the survey period was approximately 31,500 cfs.



Attachment 7. Best-fit linear water surface slopes of delineated segments, determined by direct observation, for surveyed water surface profiles of the Missouri River by the Omaha District in September 2009**.**



Attachment 8. Water surface profiles of the Missouri River surveyed by the Kansas City District at 164 locations from Rulo, NE to St. Louis, MO in August/September 2009. Discharge from Gavins Point Dam during the survey period was approximately 28,500 cfs.



Attachment 9. Best-fit linear water surface slopes of delineated segments, determined by direct observation, for surveyed water surface profiles of the Missouri River by the Kansas City District in August/September 20.